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MIGRATORY BEHAVIOR OF ADULT SPRING CHINOOK SALMON IN THE WILLAMETTE RIVER AND ITS TRIBUTARIES’

COMPLETION REPORT

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EXECUTIVE SUMMARY

- Migration patterns of adult spring chinook salmon above Willamette Falls appeared to differ depending on when the fish passed the Falls; there was considerable among-fish variability as well.

- Early run fish often terminated their migration for extended periods of time; this appeared to be associated with increased flows and decreased temperatures.

- Mid run fish tended to migrate steadily upstream at a rate of 30-40 km/day.

- Late run fish frequently ceased migrating or fell back downstream after migrating 10-200 km up the Willamette River or its tributaries; this appeared to be associated with the warming of the water during the summer and resulted in considerable mortality.

- Up to 40% of the adult salmon entering the Willamette River System above Willamette Falls (i.e. counted at the ladder) may die before reaching upriver spawning areas.

- Up to 10% of the fish passing up over Willamette Falls may fail-back below the Falls; some migrate to the Columbia River or lower Willamette River tributaries.

- If rearing conditions at hatcheries affect timing of adult returns because of different juvenile development rates and improper timing of smolt releases, then differential mortality in the freshwater segment of the adult migrations may confound interpretation of studies evaluating rearing practices.

INTRODUCTION

We describe in detail the return migration of adult spring chinook salmon (Oncorhynchus *tshawytscha*) in the Willamette River (Oregon) from 1989 through 1992, to identify potential sources of adult spring chinook mortality or disappearance in the river above Willamette Falls (Fig. 1). In the last 10 years up to 40% of the adult spring chinook salmon recorded past the Oregon Department of Fish and Wildlife (ODFW) viewing window at Willamette Falls have remained unaccounted for upstream (1987, Bonneville Power Administration Program Measures, Section 600). Our study attempts to determine the reason for the apparent loss, and suggest strategies to overcome it.

Our research is part of a larger investigation on the migratory performance of Willamette Hatchery spring chinook salmon juveniles reared under various density, water manipulation and oxygenation strategies. The oxygenation study at Willamette Hatchery conducted by the Oregon Department of Fish and Wildlife (ODFW) is dependent on a tight experimental design relating hatchery practices (experimental rearing regimes) and adult tag returns. Our study of adult migration provides data which should help determine the number and frequency of expected tag returns at the hatchery. In addition to describing the general migratory tendencies of returning adults in the Willamette River, we investigated the possibility that fish in different phases of the run might exhibit specific differences or characteristic patterns with respect to migratory behavior (i.e., rate of movement, extent or success of migration, etc.).

Relatively little is known about the migratory behavior of chinook salmon on their spawning run. Upstream migration for ocean-type (fall run) chinook has been reported to occur mainly during daylight (Neave 1943). Stream-type (spring run) chinook reportedly had poor fidelity to their release tributary, whereas ocean-type fish showed very strong fidelity (Rich and Holmes 1928). These observations for ocean-type chinook are supported by Quinn and Fresh (1984) who found 98.6% fidelity to their natal stream among chinook of four brood years from a hatchery in a lower Columbia River tributary. Juveniles that were older at release were the most likely to stray as adults. Healey (1991) suggested that straying in stream-type chinook may be explained as they naturally undergo several downstream migrations, and selection may therefore impose very early imprinting; ocean-type chinook tend to remain where they were hatched until their short, rapid outmigration, and therefore may imprint relatively later. McIsaac and Quinn (1988) studied both resident and transplanted chinook from an upriver population, and found that transplanted fish returned poorly. The influence of heredity in homing behavior is supported in their work [see also Quinn, et al. 1991, and Labelle 1992 for more recent information on chinook and coho, (Oncorhynchus *kisutch*) straying]. Most recent studies of migratory behavior of adults include the telemetry work of J. Eiler (personal communication) in Alaskan transboundary rivers near Juneau, T. Bjornn et al. (personal communication) in the mainstem -Columbia and Snake Rivers, G.

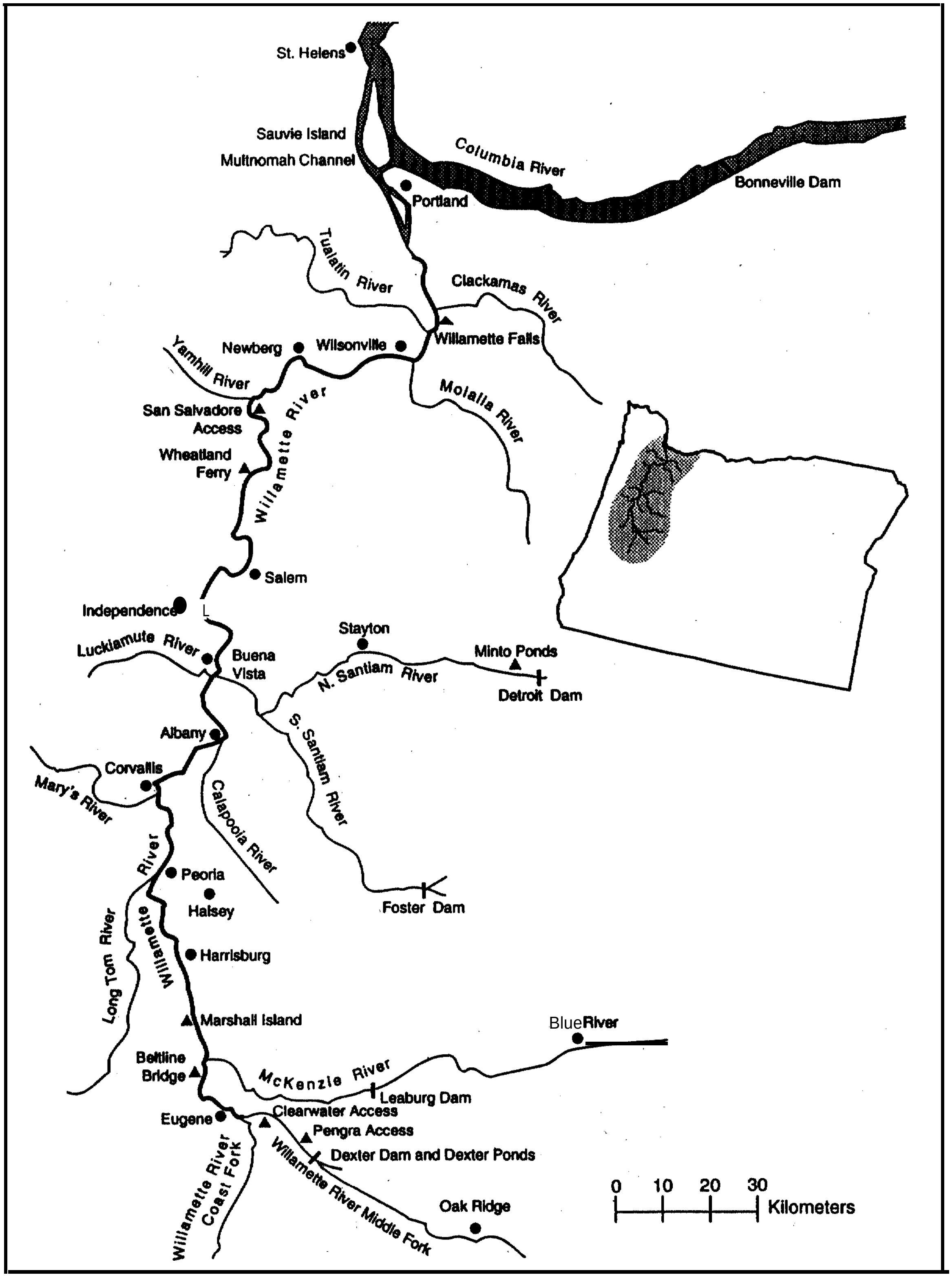


Figure 1. The Willamette River study area, showing the tributaries, dams, cities, and other areas mentioned in the text.

Mendel (personal communication) in the Snake River, and E. Hockersmith (personal communication) in the Yakima River basin. These projects primarily rely on fixed site recording stations requiring the fish to swim past a particular location to be contacted. Our study relied primarily on searching for the fish with boats during their migration.

MATERIALS AND METHODS

In May of 1989 we captured and tagged with stomach-implant radio transmitters five adult chinook salmon at Willamette Falls, West Linn, Oregon as a pilot effort. In subsequent years we captured and tagged groups of fish in April, May, and June, chosen to represent the early, middle, and late phases (respectively) of the adult spawning run.

We captured adult salmon in the lower Willamette River at Willamette Falls using the cul-de-sac ladder (opening #1) of the Willamette Falls fishway maintained by ODFW. The trap consists of a viewing window, pneumatically operated gates at the head and tail of a concrete pool, diversion Denil ladder, and anaesthetizing tank (Fig. 2). When the chinook were sufficiently calmed in an anesthetic dose of tricaine methanesulfonate (50 mg/l MS-222, buffered with 100 mg/l $NaHCO_3$), we evaluated their external condition, and began the tagging procedure on fish considered healthy and capable of upstream migration. We measured fork length to the nearest 0.5 cm with a tape rule while cradling each fish under water. Each fish was then weighed to the nearest 0.5 kg after being placed in a wet burlap bag and suspended from a spring scale. We collected two scales from each side of the fish, above the lateral line, and just anterior to the dorsal fin of each fish for age determination. We then implanted in the stomach of each fish a radio transmitter manufactured by Advanced Telemetry Systems (Isanti, MN) with these specifications: size 6 X 20 cm, weight in water 23 g (in air 13 g) battery life 70 days or longer, frequency 48-49 MHz. Where we worked in the Willamette these tags had a minimum range of about 1 km. The radio was inserted through the esophagus using a plastic pipette as a trochar through which the antenna was strung. Depending on the size of each fish the 35 cm antenna was crimped so that the last 5 to 20 cm extended back from the fish's mouth. In 1992 we photographed the left side of each fish tagged. We then gently lifted each fish from the anesthetic bath into a recovery trough, from which it could volitionally re-enter the fishway; the gate blocking downstream but not upstream movement remained in place for at least 48 hours after release of the last fish.

In 1991 Portland General Electric's Sullivan Plant (hydroelectric) suspended operation for a month from mid-April to mid-May. In the absence of sufficient attraction water for the cul-de-sac portion of the fish ladder, chinook were not using this avenue to pass over Willamette Falls. Since the cul-de-sac is the only leg of the fishway at Willamette Falls equipped with a trap facility, it was

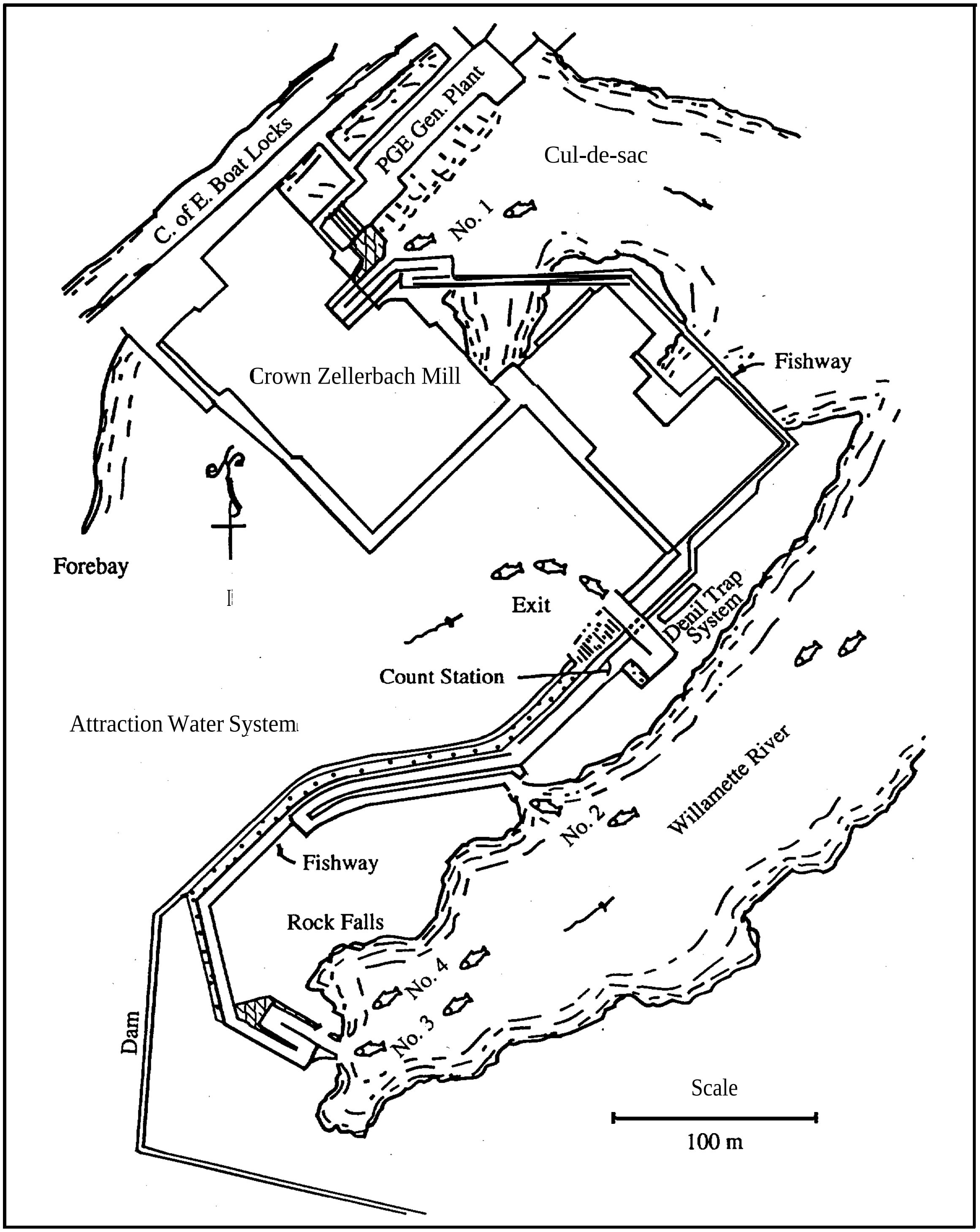


Figure 2. Willamette Falls area. The fishway maintained by the Oregon Department of Fish and Wildlife (ODFW) is shown, along with the Corps of Engineers locks, Portland General Electric hydropower plant, and Crown Zellerbach paper mill. Numbers refer to entrances to the fishway for adult passage. Graphic courtesy of ODFW.

necessary for us to collect early run salmon using an alternate approach. On 23 April the fishway was de-watered; during this time we sequestered 27 adult spring chinook into a shallow pool directly in the ladder. A 34 1 plastic tub was employed as an anesthetic bath. Fish were netted and immediately transferred to this tub, where they were anesthetized, measured and implanted with radios. These fish were not weighed and scale samples were not taken. Immediately following the tagging procedure, fish were returned to the fishway and monitored for recovery.

Our tracking strategy emphasized first obtaining locations on as many fish as possible to determine patterns of movement; second we followed individual fish to learn about diel patterns of movement, habitat preferences and other aspects of their individual and collective behavior. For the most part, the upstream (and in some instances, downstream) progress of radio-tagged adults was monitored from boats; a jet boat was used below Eugene, and a drift boat in the upper Willamette between Dexter Dam and Eugene. In 1992 we tracked adults up the Santiam and McKenzie systems; because of low water depth this was largely accomplished using a drift boat or by tracking from the road by truck. A loop antenna and tripod was mounted in the bow of the boat, and river maps (*Willamette River Recreation Guide*, Oregon State Marine Board) along with river mile signs along the river, were used to establish fish locations to the nearest 0.5 km.

The mean pulse rate of our transmitters was about 120 pulses per minute, so receiver scan intervals as brief as two seconds per frequency allowed the unambiguous identification of individual fish, once in range. Our tracking strategy varied slightly from year to year and depended on when fish were tagged; generally we tracked fish each day for the first week after tagging, and thereafter every other day.

In 1992 we implanted 10 chinook with tags equipped with temperature sensing circuits and with the same specifications described above. A regression provided by the manufacturer allowed calculation of ambient temperature based on the pulse rate. We also tracked individual fish for continuous periods of over 24 hrs.

About three weeks after marking, fish were located using aircraft. A helicopter provided by The Bonneville Power Administration (BPA) was used to find several fish below the Falls in 1991. In 1992 fixed wing aircraft provided by the Oregon State Police provided coverage of entire Willamette basin. Heights of from 700 to 2,000 ft. above ground level at speeds of 75 knots allowed effective scanning of about 30 frequencies. To determine more accurately the overall pattern of migration in each group of fish, in 1992 we employed two data logging receivers (SRX_4000, LOTEK Engineering, Newmarket, Ontario, Canada), one near the mouth of the Santiam River (Kilometer 174) and a second near the mouth of the McKenzie River (Kilometer 280). Receivers were adjusted so that a single antenna received signals at both high and low gain, and the path each fish took could be determined therefrom.

During the 1991 through 1993 field seasons we maintained receivers at ODFW terminal weirs on the middle fork Willamette (Dexter), North (Minto) Ponds and South Santiams (hatchery), and personnel there monitored arrival of the fish. We also tracked from the roads around the salmon hatchery on the McKenzie River to determine when fish arrived there; the dam is laddered so not all fish stop at that hatchery.

During our tracking we noted dead chinook in the river, and made observations on flow, temperature, and weather. In 1992, because the temperature tags pulsed rapidly in the elevated temperature out of water, we learned to locate individual tags discarded when fish had died.

In 1990 and 1991 we used aircraft and a single data logging station on the Columbia (just below Bonneville Dam) to assess the movement of fish out of the Willamette system and back up the Columbia. We looked for fish in the lower Willamette River, Multnomah Channel, the Columbia River between Sauvie Island and Bonneville Dam, and in all tributaries in these areas.

RESULTS

We trapped and tagged chinook salmon during three months, April, May and June, except for 1989 when we tagged only five fish (in May). Based on historical counts of fish at the Willamette Falls ladder maintained by ODFW, we determined that these months represented the early, middle and late portions of the spring chinook salmon spawning migration on the Willamette River. We could not know the release location for these fish; but they include the Molalla River, the North and South Santiam Rivers, the Mckenzie River, or the middle fork of the Willamette River. The timing of adult migration for all years of our study is shown in Figure 3.

Description of Fish Tagged

We handled and tagged 224 adult spring chinook (Table 1). We marked fish designated as early run from 17 April to 23 April, middle run fish as early as 14 May and as late as 23 May, and late run fish from 8 June to 26 June, depending on the year. Their average length was from 77 to 90 cm and average weight was from 7 to 9.5 kg. Their age based on scale examination was from three to six years; the chinook we studied had therefore spent from two to five years at sea.

Figure 3. Daily counts of adult spring chinook salmon past the ODFW viewing window at Willamette Falls during the spawning migration, 1989 through 1992. Data provided by ODFW.

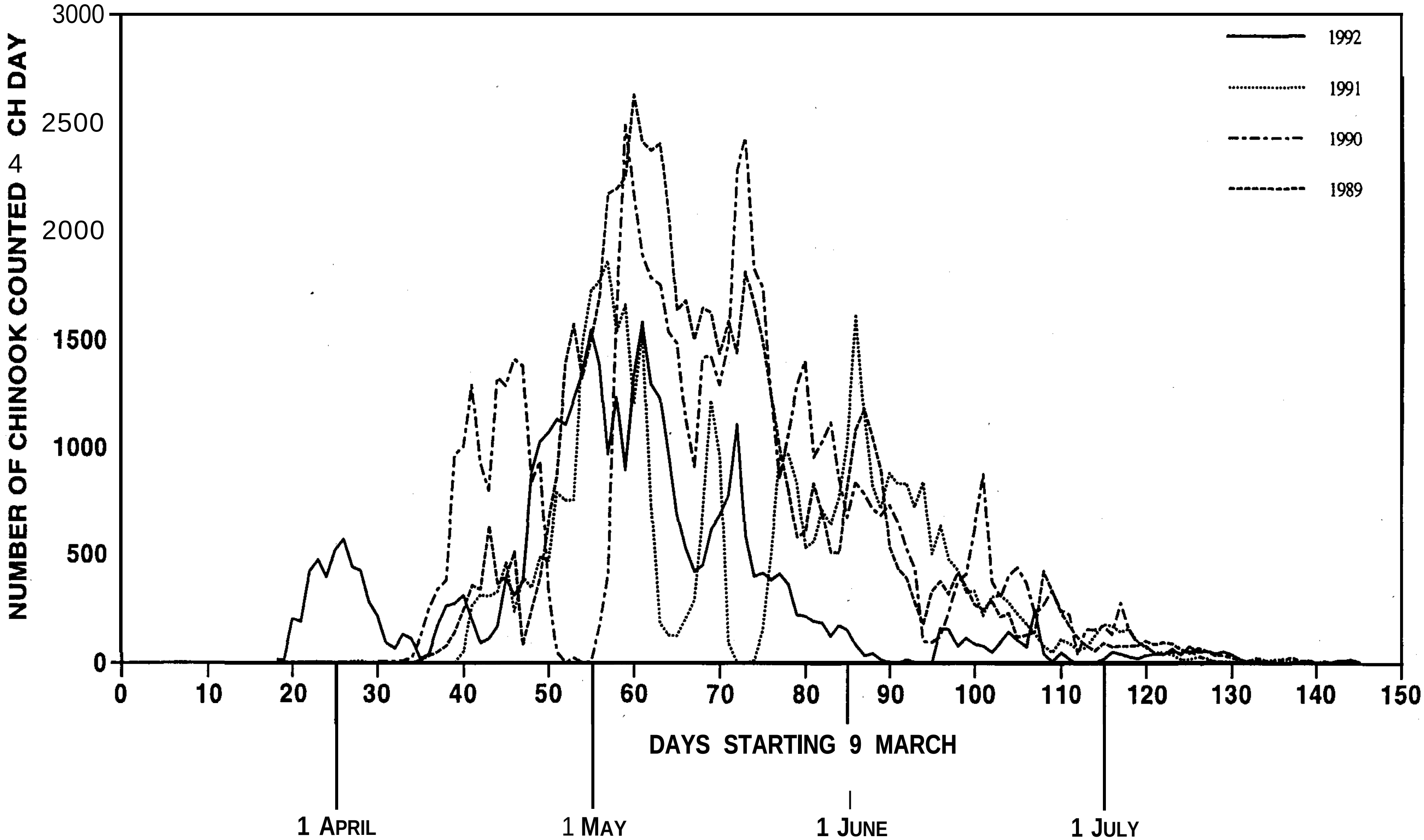


Table 1. Description of adult spring chinook salmon captured, implanted with radio transmitters, and released into the fish ladder at Willamette Falls (River Km 50.5) during 1989,1990 ,1991, and 1992.

Period During Run	Date Fish Tagged	No. Rsh Tagged	Length (cm)		Weight (kg)		Age (yrs)	Sex		
			Average	Range	Average	Range	Range	Male	Female	Unk
	1989									
Middle	23-May	5	76.7	67.0-89.4	6.9	4.5-10.0	---	0	4	1
	1990									
Early	PO-Apr	15	81.3	68.0-95.0	8.4	4.8-12.3	3+-4+			---
Middle	23-May	17	90.0	72.0-92.0	7.6	5.0-13.0	3+-4+			---
Late	25-Jun	19	83.5	65.0-99.0	9.3	5.3-14.8	3+-4+			
	1991									
Early	23-Apr	27	82.9	64.0-99.0	---	---	---			---
Middle	28-May	28	80.3	65.0-102.0	7.8	4.3-14.8	3-4+			---
Late	26-Jun	30	85.0	72.0-106.0	8.9	4.0-16.8	3+-4+			---
	1992									
Early	17/18 April	25	85.0	67.0-97.0	8.7	4.8-12.4	3–6	11	10	4
Middle	14/15 May	30	81.4	62.0-104.0	7.4	3.9-12.9	3–6	19	10	1
Late	8-Jun	28	80.2	61.0-95.0	6.8	3.5-12.4	3–6	13	15	0
	Total	224								

Patterns in the Spawning Migration

1989. The upriver movements of adults, tagged in 1989 are shown in Figure 4. Data are expressed as distance traveled upstream as a function of time; the slope of any line gives the average velocity over a given reach of river. One adult reached Dexter Dam on day 20 post release, an overall speed of 16 km / d. One fish remained in the fishway for six days before beginning its migration at a rapid rate of 72 km in two days. Two others moved upstream, then stopped downstream of the Santiam River. We believe these fish subsequently died, or regurgitated their tags.

1990. The upriver movements of adults tagged in 1990 are presented in Figures **5-7. Early-run adults** were tracked intensively from 20 April to 21 May (Fig. 5). In general, this group of fish moved upstream relatively slowly averaging about 6 km / day and irregularly, and with many individuals moving back downstream, following an upstream migration in the days immediately following the tagging procedure; on the day after tagging, only three of 15 tagged fish had exited the fishway. Early-run fish demonstrated a high degree of individual variability with respect to upstream migration. One fish remained in the fishway for six days; in contrast, the lead fish over this same period had moved 135 km upstream. One individual never exited the fishway; subsequently (in the week prior to tagging mid-run fish) this transmitter was discovered in a carcass during the course of de-watering the fishway.

During the course of tracking early-run fish, only two of 15 tagged individuals made considerable upstream progress, i.e., past Corvallis. One fish eventually reached the upper Willamette; this fish was located (during the course of tracking mid-run fish) approximately 16 km below Dexter Dam, 48 days post-tag / release. The fastest fish during this phase of the run was observed to travel 35 km in one day (1.5 kmph). This same individual left the mainstem Willamette and swam 4 km up the Santiam River on day six post-tag / release. One other early-run fish was observed to move up the Santiam River as well, and was subsequently located below Foster Darn, the end point for fish in this river. In general many fish held for several weeks in the river immediately above or in a few cases below Willamette Falls after very short migrations.

Mid-run adults were tracked from 23 May to 16 June (Fig. 6). In contrast to the early-run group, these fish resumed upstream movement almost immediately after we tagged them. On the day following tagging, 13 of 16 fish had moved out of the fishway, and the lead fish was found 47 km upstream of Willamette Falls. One day later all fish had exited the fishway (as with the early adults, one fish never left the fishway; at the end of this phase of the run the fishway was inspected and the tag was found).

In sharp contrast to early-run fish, mid-run fish moved upstream quite rapidly, and displayed much less individual variability in their movement

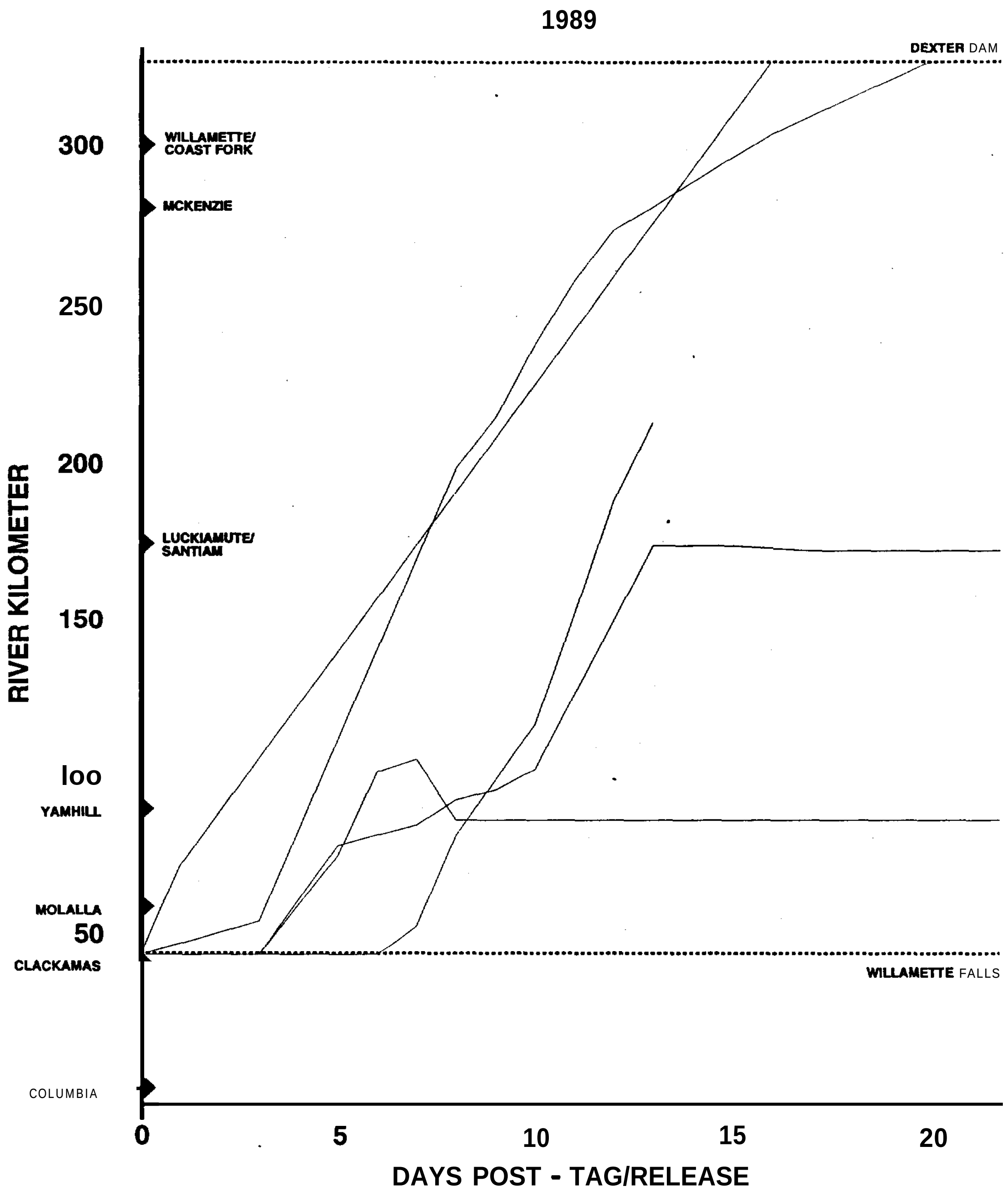


Figure 4. Location and movement of mid-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1989. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Day 0 = 23 May; N = 5.

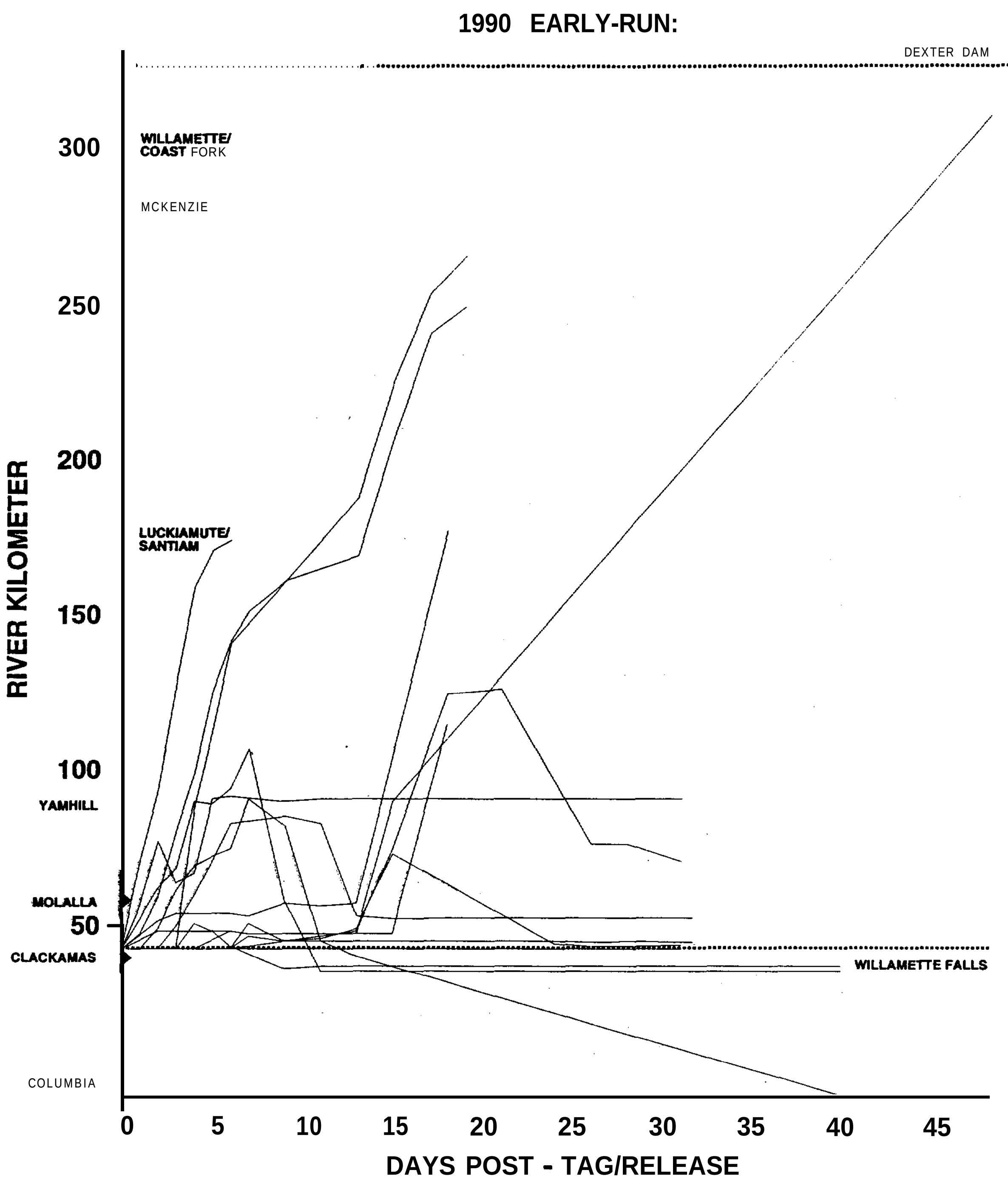


Figure 5. Location and movement of early-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1990. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Detail of fish downstream of Willamette Falls shown in Figure 8. Day 0 = 20 April; N = 14.

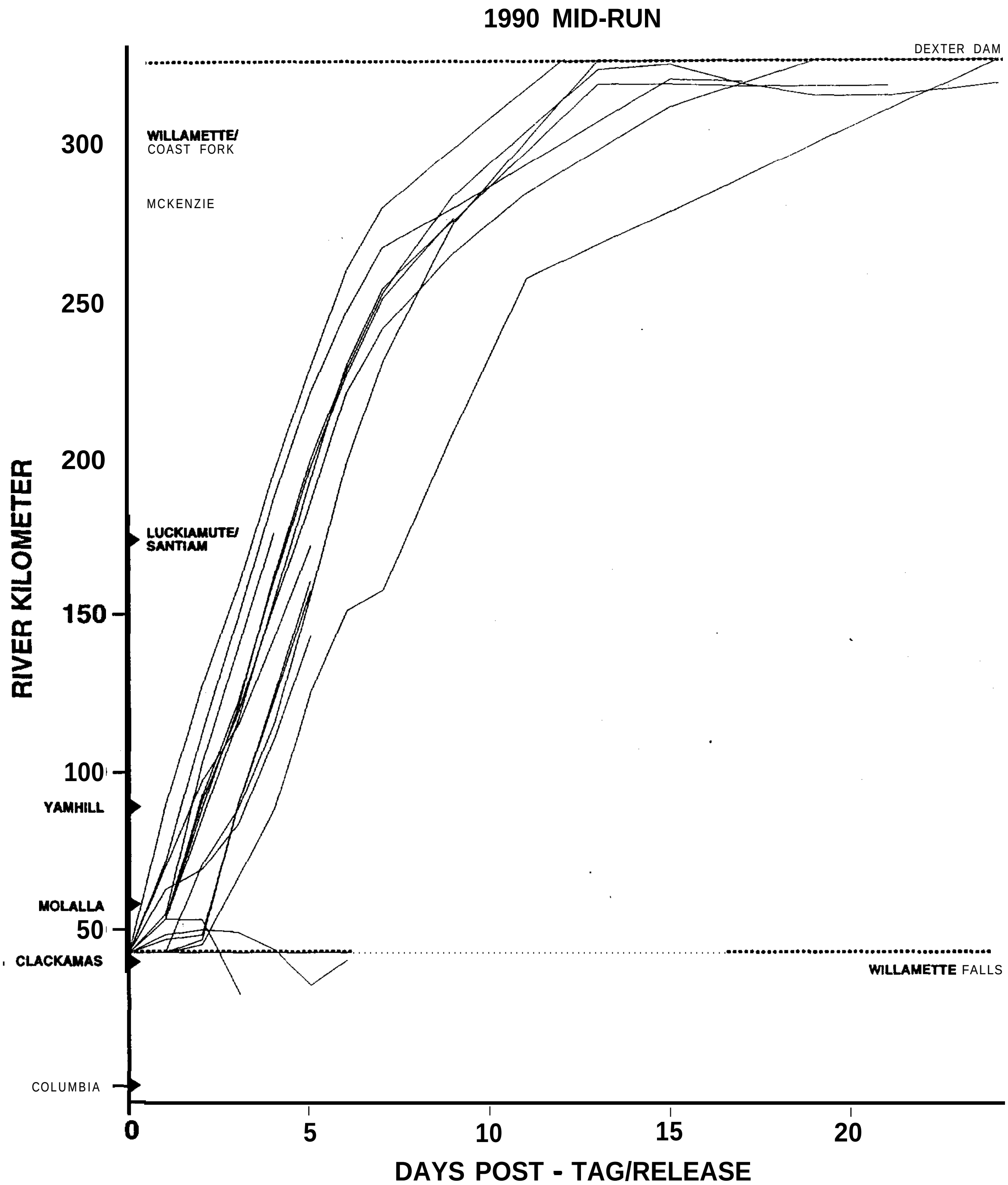


Figure 6. Location and movement of mid-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1990. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Detail of fish downstream of Willamette Falls shown in Figure 8. Day 0 = 23 May; N = 16.

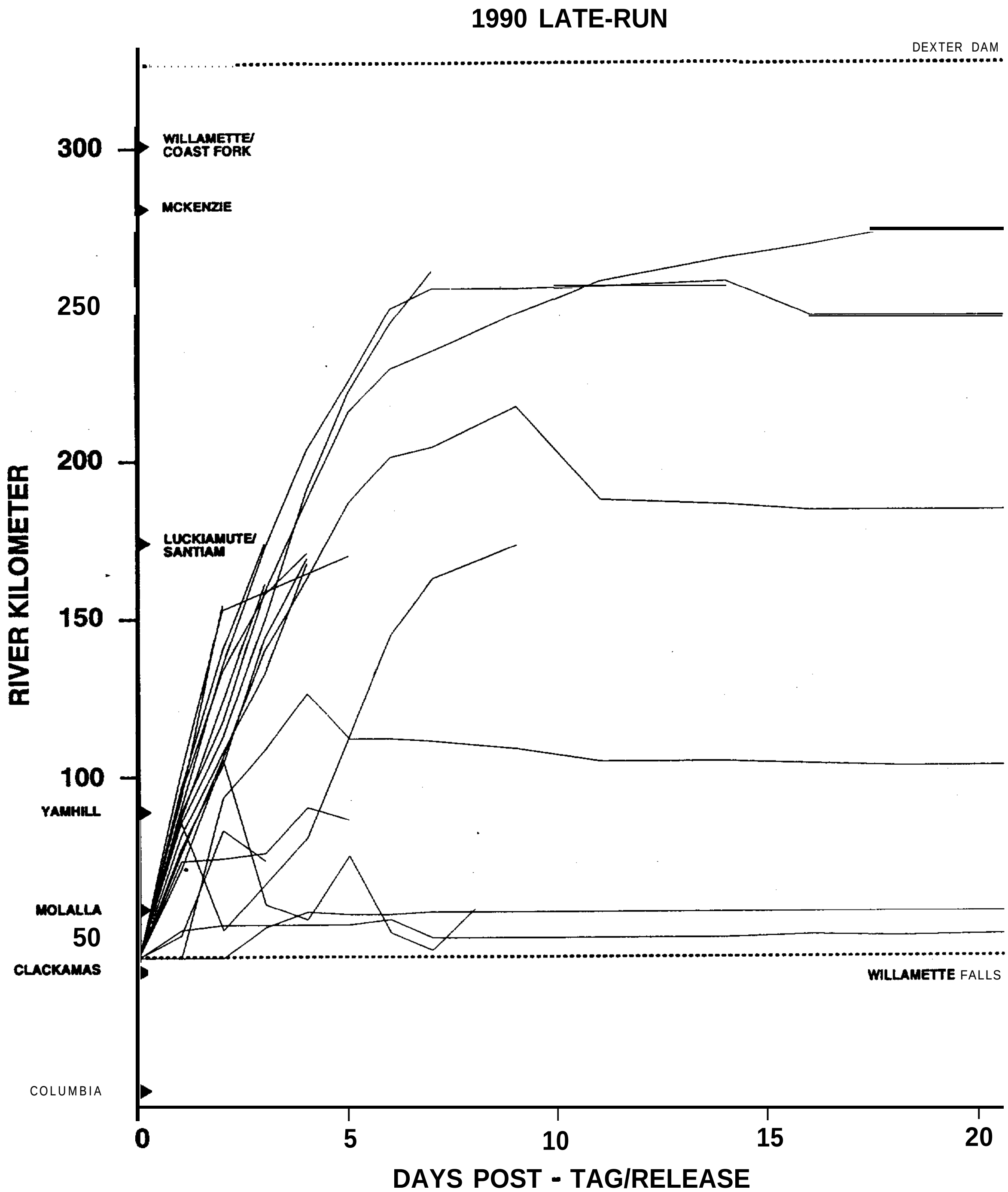


Figure 7. Location and movement of late-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1990. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Day 0 = 25 June; N = 18.

patterns. The fastest fish during this phase of the run covered 43 km in one day (1.8 kmph). The behavior of this individual was not unusual, however, as all of the mid-run fish (with the exception of two fish which moved downstream, see below) tended to move upstream at a rate of 32-40 km / d during the first week after tagging.

Five of 16 fish ultimately left the Willamette and swam up the Santiam River; one of these was later located below Foster Dam. None of the mid-run fish were found up the McKenzie River, however all of the fish which progressed this far slowed dramatically upon reaching the confluence of the McKenzie and Willamette Rivers. Fish which had been moving at an almost linear rate up to this point, proceeded upstream at average velocities ranging from 3-15 km / d after passing the mouth of the McKenzie. Seven fish ultimately progressed upstream as far as Dexter Dam, or within 16 km of the dam. In fact, two of our radio tags were recovered by ODFW personnel during routine handling of adults they collected for spawning at Dexter Pond.

Unlike the majority of mid-run fish, two individuals exited the **fishway** and dropped back downstream of Willamette Falls. We tracked one of these fish out to within 5 km of the Columbia, after which it presumably re-entered the Columbia River; our efforts to locate this individual subsequently, either from boat or helicopter, were unsuccessful. Another fish moved downstream as far as KM 32, after which it "disappeared," i.e., could not be located in the lower Willamette River. This fish must have turned around, swam back upstream 10 km, and entered the Clackamas River, as it was caught by an angler just below the Clackamas Hatchery on day 10 after tagging and release.

Late-run fish were tracked from 25 June to 20 July (Fig. 7). Like mid-run fish, late-run fish resumed upstream migration almost immediately after being tagged; 16 of 18 fish had exited the **fishway** and the lead fish had moved 59 km upstream the day after tagging (59 km / day) (this observation represents the greatest distance traveled upstream in one day for any adult this year). All fish had exited the **fishway** by day three post-tag / release (as in previous tagging, one individual never moved out of the **fishway;** at the termination of the study the **fishway** was again de-watered and the carcass with radio-tag was found).

The majority of radio-tagged late-run fish initially resembled mid-run fish, in that they made rapid upstream progress at a rate of 2440 km / d. However this behavior was sustained by these individuals for only a few consecutive days, after' which they either entered the Santiam River or proceeded upstream past Corvallis at considerably reduced velocities. Furthermore, a minority of late-run fish more closely resembled early-run fish, in that they remained for the most part in the lower river and displayed considerable individual variation in their movement patterns.

Eight of 18 fish tagged as the late-run swam up the Santiam River. Only three individuals proceeded upstream past Corvallis. One of these was eventually "lost" and may have moved up the McKenzie River, as efforts to locate this fish in the upper Willamette were unsuccessful. The other two fish recorded past Corvallis presumably died or regurgitated; we recovered one tag by diving.

Although none of the late-run fish were observed to "fall back" below Willamette Falls, one individual demonstrated a remarkable tendency to move first upstream and then downstream. It was located 28 km upstream of the. fishway on the first day post-tag/release; On day two, this fish had moved upstream an additional 34 km, however on day three we located it 45 km back downstream. The next day this fish had "backed up" an additional 6 km, but one day later it was located 22 km upstream of the previous day's location. On the next day this fish had turned back downstream 24 km, and the day following had backed up an additional 6 km. We eventually received this radio tag from an angler who had caught the fish in the Molalla River.

Of particular interest were several individuals which we observed to "back up", move downstream, or fall back over the dam after making upstream progress (movement patterns for these fish are plotted in Figure 8). In fact, three fish were eventually located at various sites below Willamette Falls. One individual in particular had progressed upstream as far as 108 km by day seven post-tag/release, but on day nine had returned downstream 50 km and then swam 5 km up the Molalla River. Two days later, this fish had reentered the Willamette River and moved downstream another 26 km. Another fish, located just below the Falls on day 13 post-tag/release, "disappeared" and could not be relocated; this individual was subsequently discovered (while tracking from the BPA helicopter) in the Multnomah Channel, west of the Sauvie Island Management Area (location 16 km in the Channel), more than one month later.

1991. The upriver movements of adults we tagged in 1991 are presented in Figures 9-11. We intensively tracked 26 **early run adults** for about one month starting 23 April (Fig. 9); a 27th fish died in the fishway. The day after tagging eight fish had exited the fishway. Salmon moved an average of 16 km/d during the first three weeks. Five fish remained in the fishway for at least one day; one remained there for six days. One fish traveled 6 km the first day.

Six fish made considerable progress upstream past Corvallis. Five fish traveled up the Santiam system, presumably to spawn there. One fish swam up the McKenzie River. Three were recorded by our data logger near the trap below Dexter Dam. A reward message on the radio-tags led to the recovery of 10 tags. One fish was recovered in the trap at the McKenzie River Hatchery, and one at Dexter Ponds on the Willamette. The others were caught by anglers, all about 10 days after tagging; one from the South Santiam, one between Independence and

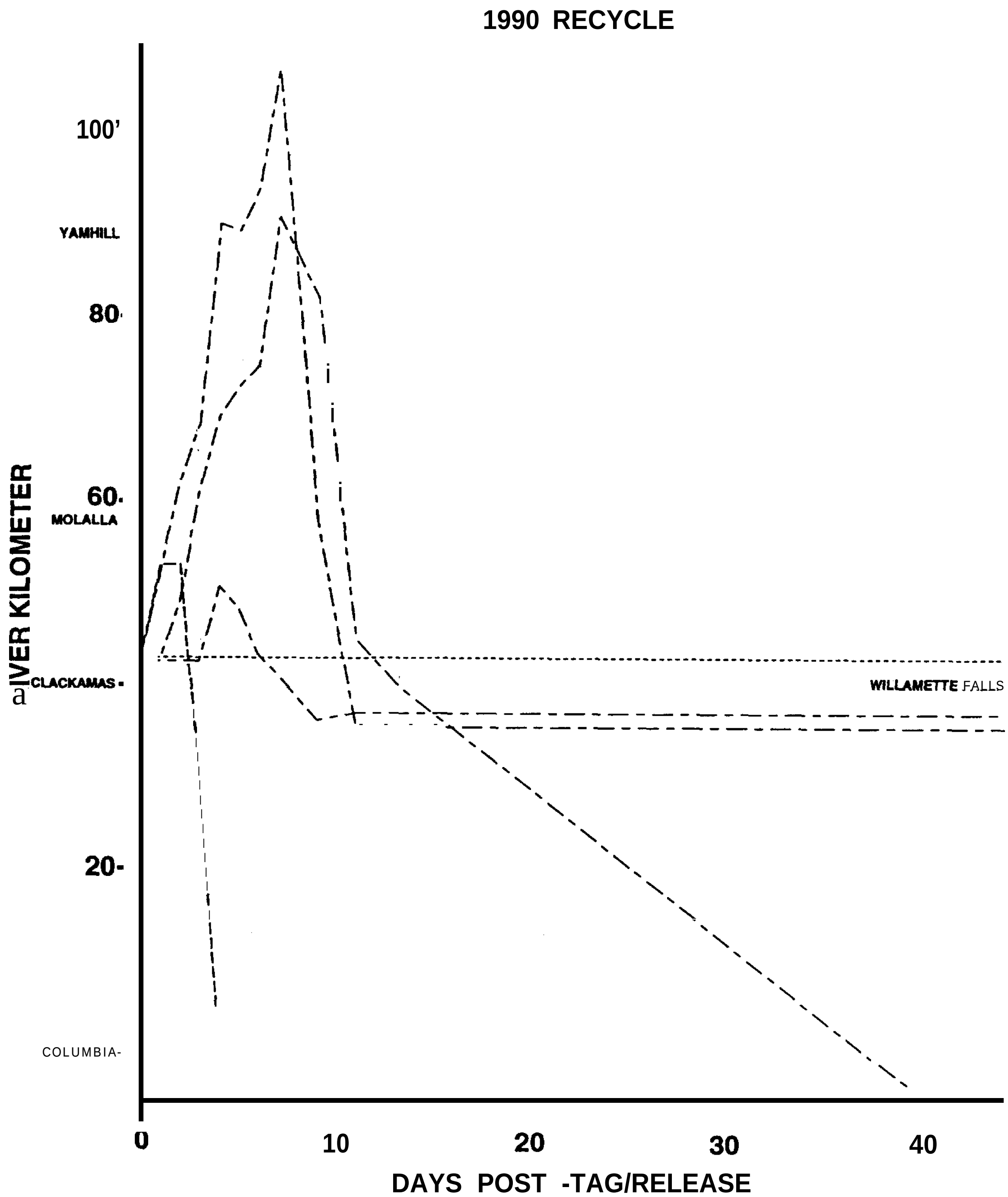


Figure 8. Detailed movements of adult spring chinook salmon radio tagged in 1990 which went below Willamette Falls; some of which made additional passes through the fishway. Early-run fish noted by dashed and dotted lines, mid-run fish by dashed lines. Data from Figures 5 and 6.

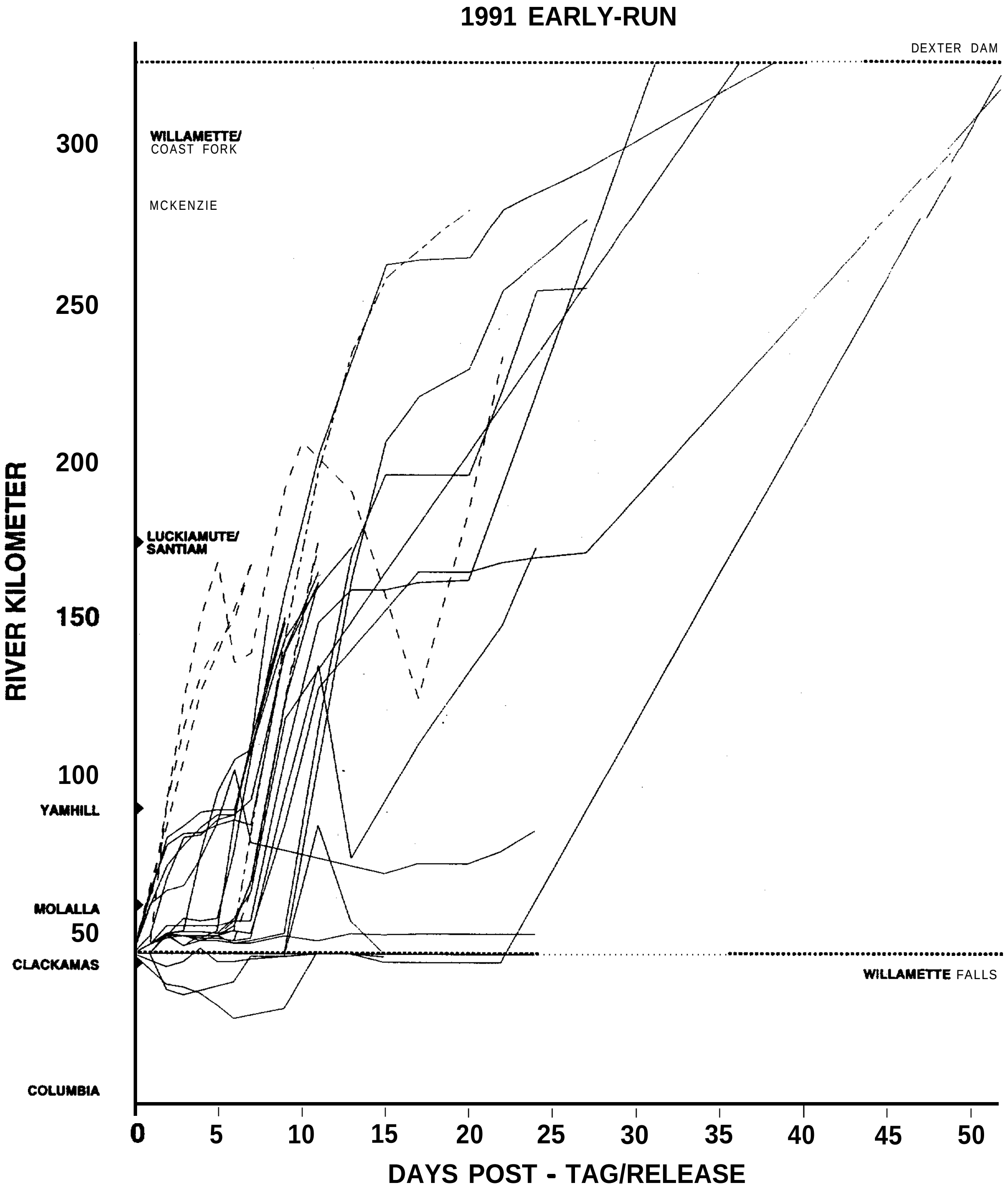


Figure 9. Location and movement of early-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1991. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Fish which swam into the McKenzie River denoted by dashed and dotted lines; fish in the Santiam River system noted by dashed lines; fish remaining in the Willamette River by solid lines. Detail of fish downstream of Willamette Falls shown in Figure 12. Day 0 = 23 April; N = 26.

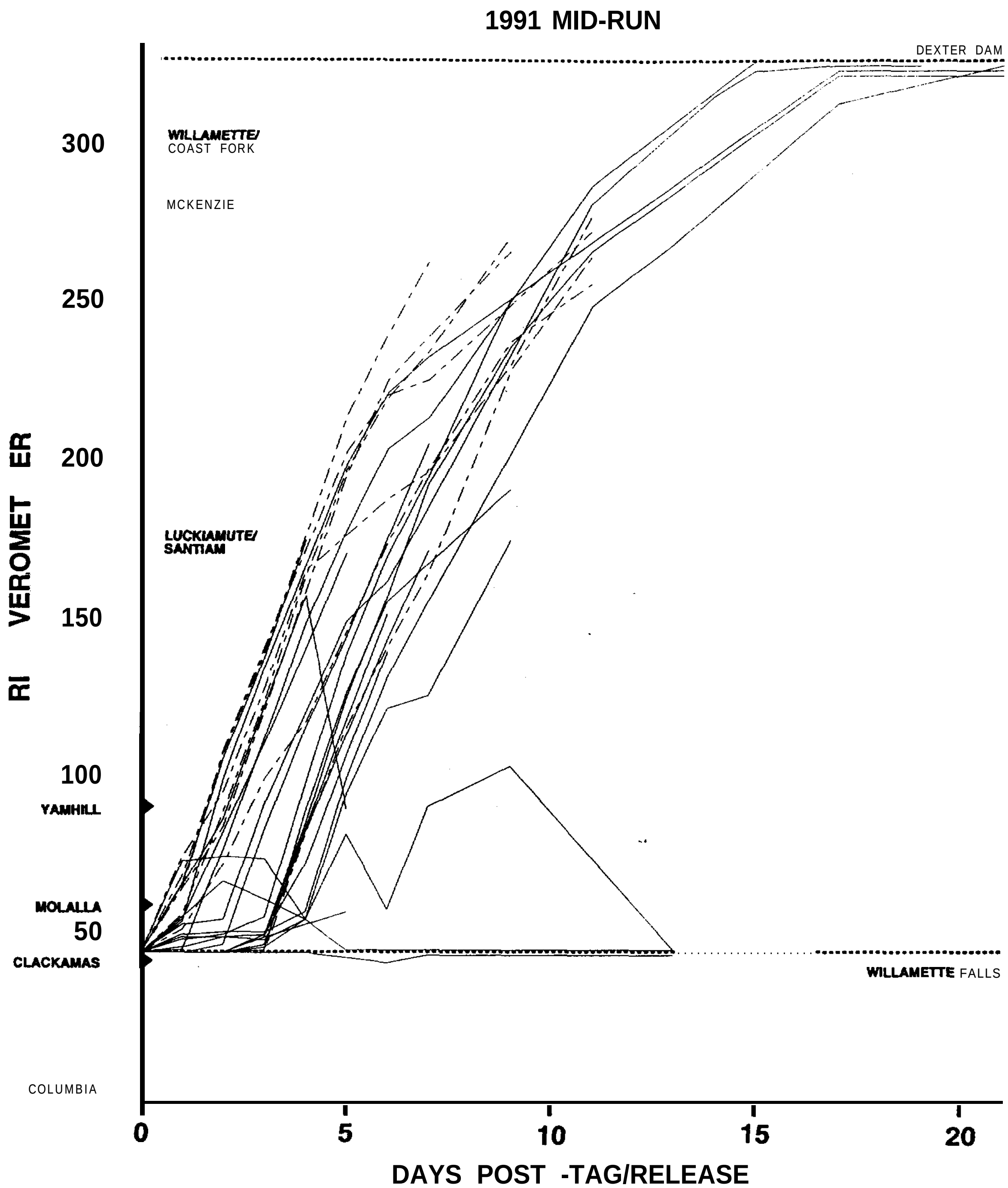


Figure 10. Location and movement of mid-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1991. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Fish which swam into the McKenzie River denoted by dashed and dotted lines; fish remaining in the Willamette River by solid lines. Detail of fish downstream of Willamette Falls shown in Figure 12. Day 0 = 28 May; N = 27.

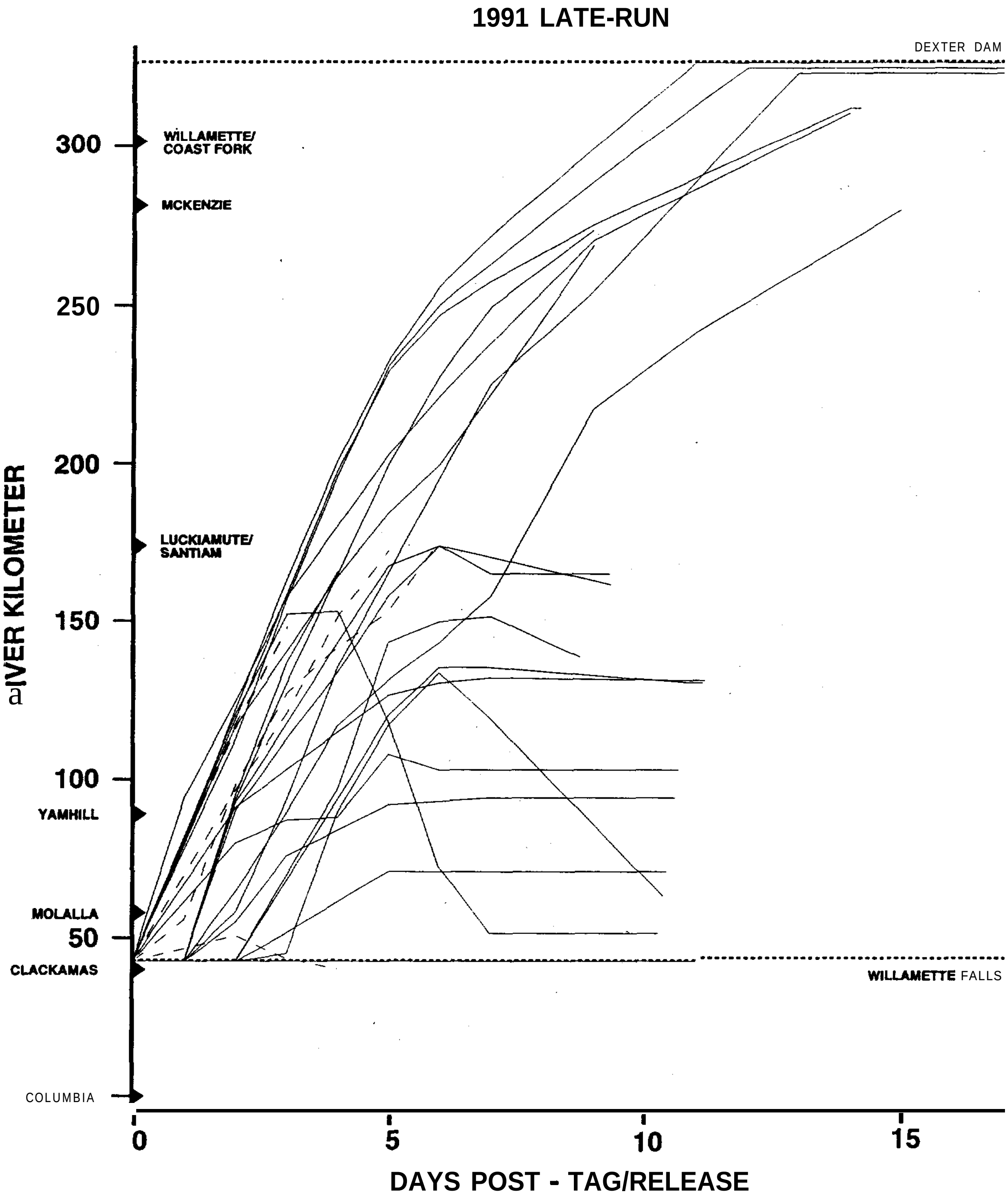


Figure 11. Location and movement of late-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1991. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Fish which swam into the Santiam River system (or Clackamas River below Willamette Falls) noted by dashed lines; fish remaining in the Willamette River by solid lines. Detail of fish downstream of shown in Figure 12. Day 0 = 26 June; N = 24.

Salem on the Willamette, four from the North Santiam, one from the McKenzie, and one in the Santiam system (exact location unknown).

The fastest fish traveled 39 km in one day (and was caught the next day by an angler). Seven fish remained about 6 km above Willamette Falls for at least four days. As occurred in 1990, three fish initially moved downstream.. One swam 10 km below the falls before traveling up to Newberg and then back to the Falls. None of these fish made a net gain in passage upstream, and all were recorded last in the vicinity of the falls.

We tracked 27 **mid-run adults** for about three weeks after they were tagged on 28 May (Fig. 10); a 28th fish presumably died in the fishway. Seven fish remained in the fishway up to four days before moving upriver. The lead fish moved 31 km upstream on the first day. The average speed of the group was 24 km/d, showing as last year the more direct migration of mid-run spring chinook salmon. The three fastest fish each covered 37 km in a single day. Once past the mouth of the McKenzie, fish traveled upriver at a reduced rate (about 10 km each day).

Thirteen fish traveled up the Willamette as far as Corvallis. Five were recorded in the vicinity of Dexter Dam, and five were located in the McKenzie. Our reward tags helped recover four of these mid-run fish. Two were trapped at Dexter, and one at McKenzie River Salmon Hatchery; the fourth was caught by an angler near Dexter Dam.

As we observed in 1990, these mid-run salmon moved more rapidly and with far less individual variation than the early-run or late-run fish. But like the previous year's cohort, three fish traveled upriver, one as far as 59 km, and then returned to the Falls.

We tracked 24 **late-run** adult spring chinook salmon tagged on 26 June for about three weeks; six other fish either died or their tags malfunctioned near the Falls (Fig. 11). Half of these fish traveled like their mid-run counterparts, but the remainder swam no further than Salem; they either died or regurgitated their tags there.

Eleven fish remained in the fishway for two to three days after tagging. The fastest fish swam 52 km in one day. Three fish entered the Santiam system. Only three reached Dexter Dam. Three fish made no significant net progress above Willamette Falls, although one traveled 16 km upstream of Salem before turning and swimming back to the Falls. One fish moved back below the Falls, swam up the Clackamas, and was then caught by an angler.

Three fish from the early group fell back below Willamette Falls (Fig. 12). One fish went as far downriver as downtown Portland, then up above Newberg (RKM 80), only to return to the Falls. Another went to Portland then returned to

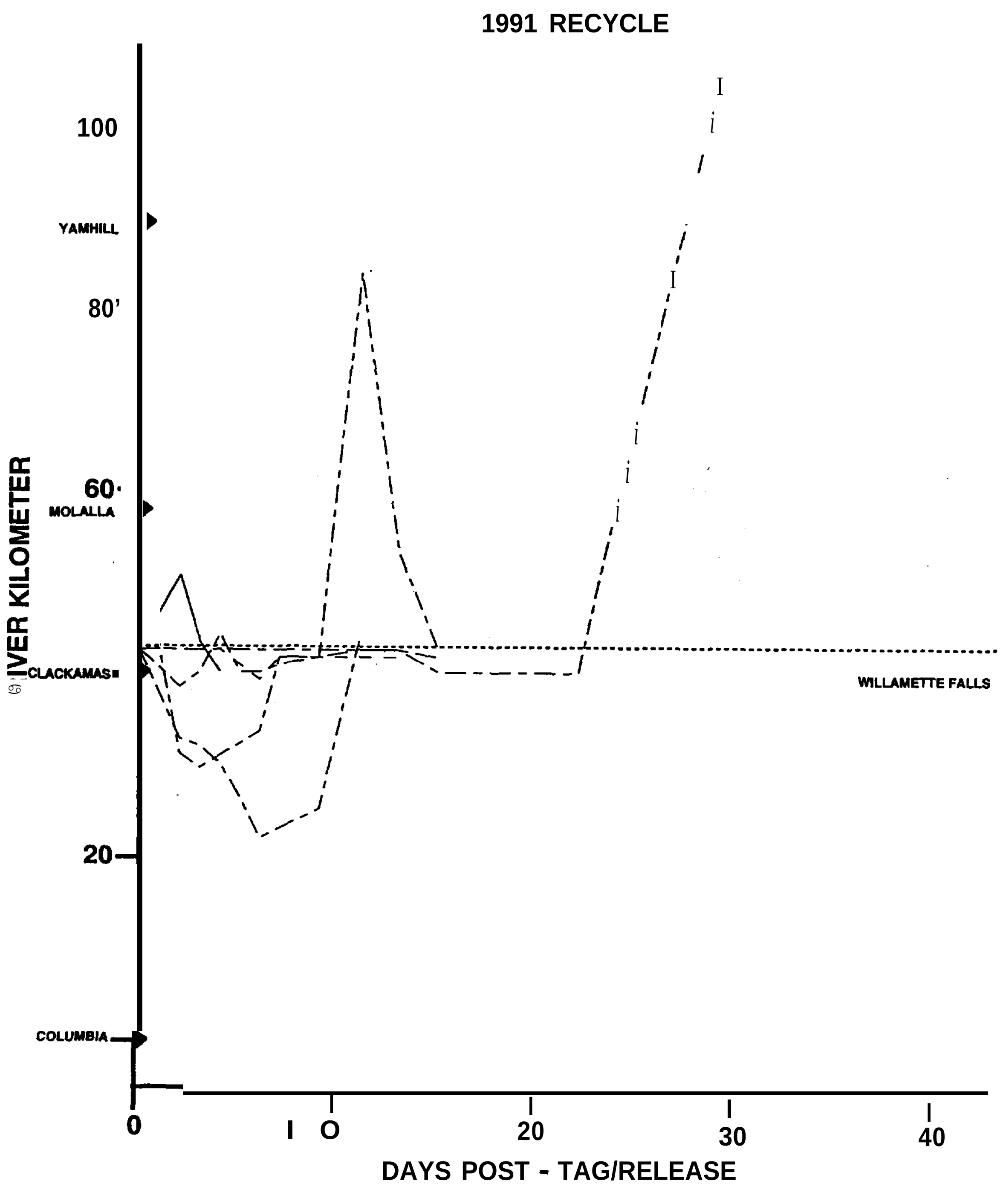


Figure 12. Detailed movements of adult spring chinook salmon radio tagged in 1991 which went below Willamette Falls; some of which made additional passes through the fishway. Early-run fish noted by mixed dashed lines; mid-run fish by dashed line; late-run fish by solid line. Data from Figures 9 - 11.

the Falls. Another fish made two trips above the Falls and therefore would have been counted twice. One fish each from the mid and late groups fell downriver; an angler on the Clackamas caught one and returned its tag.

1992. The upriver movements of adults we tagged in 1992 are presented in Figures 13-16. We tracked 25 **early run adults** for up to five months starting 18 April (Fig. 13). We recorded 23 fish above the fish ladder; either the transmitters of two others failed or detuned, or the fish swam quickly downstream and out of range. Salmon moved an average of 8 to 26 km/d during the first two weeks, depending on which tributary they followed. Our data presentation for 1992 follows individual tributaries because we focused on individual fish and where they went.

Nine fish (36%) reached hatchery traps at Dexter, Foster or Minto. Anglers caught five more, and returned their transmitters to us. Eight fish (32%) moved into the North Santiam River, and all but one stayed there. Of the nine fish which continued up the Willamette above the Santiam, only four- swam above the mouth of the McKenzie; those remaining may have been headed for other tributaries. We believe that the six fish which moved back downriver died; we either heard their signals for extended periods in the same place, or found their tags; we have no evidence of tag regurgitation. One fish moved back over the falls a few kilometers, then reversed direction and migrated to the Dexter trap; this is an exception to our general observation that fish which stop their migration upstream are those which die before spawning. Another salmon traveled as far as the North Santiam (15 KM from the Willamette) then fell back to Newberg. Another went up the South Santiam then fell all the way back to Willamette Falls. A fourth went into the Mainstem Santiam a few kilometers, fell back to below Salem and was caught by an angler.

We tracked 30 **mid-run adults** for up to four months after tagging them on 14 and 15 May (Fig. 14). All fish made progress upstream less than a day after being tagged. Their average speed during the first week was 16 to 31 km/d, depending on to which river they were headed. Except for those fish which stopped migrating (see below), fish that reached the hatchery areas maintained at least an average speed of at least 16 km/ d.

Twelve fish (40%) reached hatchery traps at Minto, Foster or the McKenzie. Anglers caught three others in the Santiam system. Seven fish each (23%) traveled into the North Santiam and McKenzie Rivers. Of the 11 fish traveling only in the Willamette, only four went beyond the Santiam River confluence, and only one beyond the McKenzie; therefore we did not determine to which river 10 fish were headed. Four of these, which swam no further than the mainstem Santiam, fell back as much as 56 km; we believe they all died before spawning. As we observed in 1990, these mid-run salmon moved more rapidly and with far less individual variation than their early- or late-run counterparts. We know that two fish died, and believe that nine others (37% of

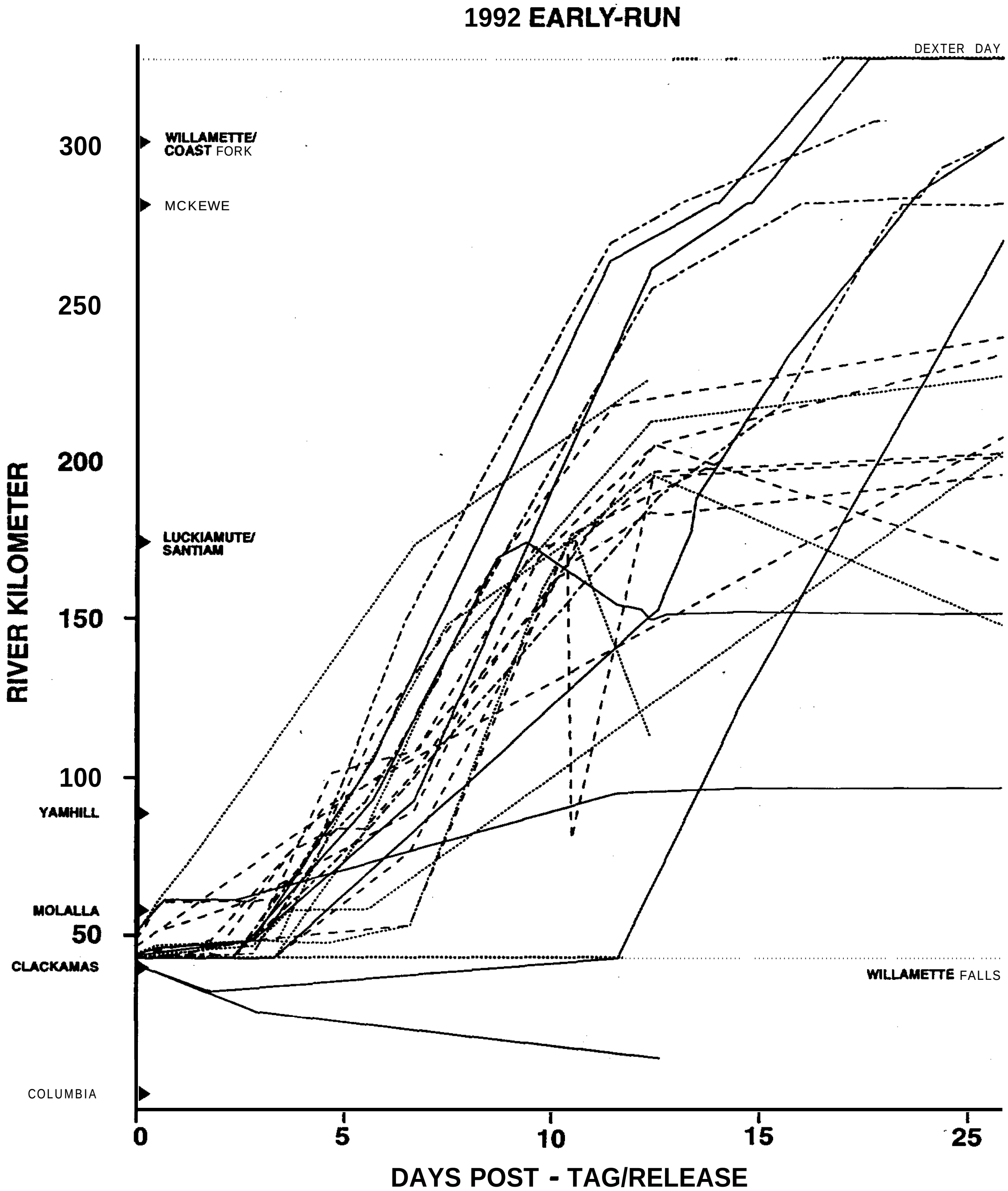


Figure 13. Location and movement of early-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1992. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Fish which swam into the McKenzie River denoted by mixed dashed lines; fish in the North Santiam River system by bold dashed lines; fish in the South Santiam River by narrow dashed lines; fish remaining in the Willamette River by solid lines. Detail of fish downstream of Willamette Falls shown in Figure 16. Day 0 = 17/18 April; N = 23.

1992 MID-RUN

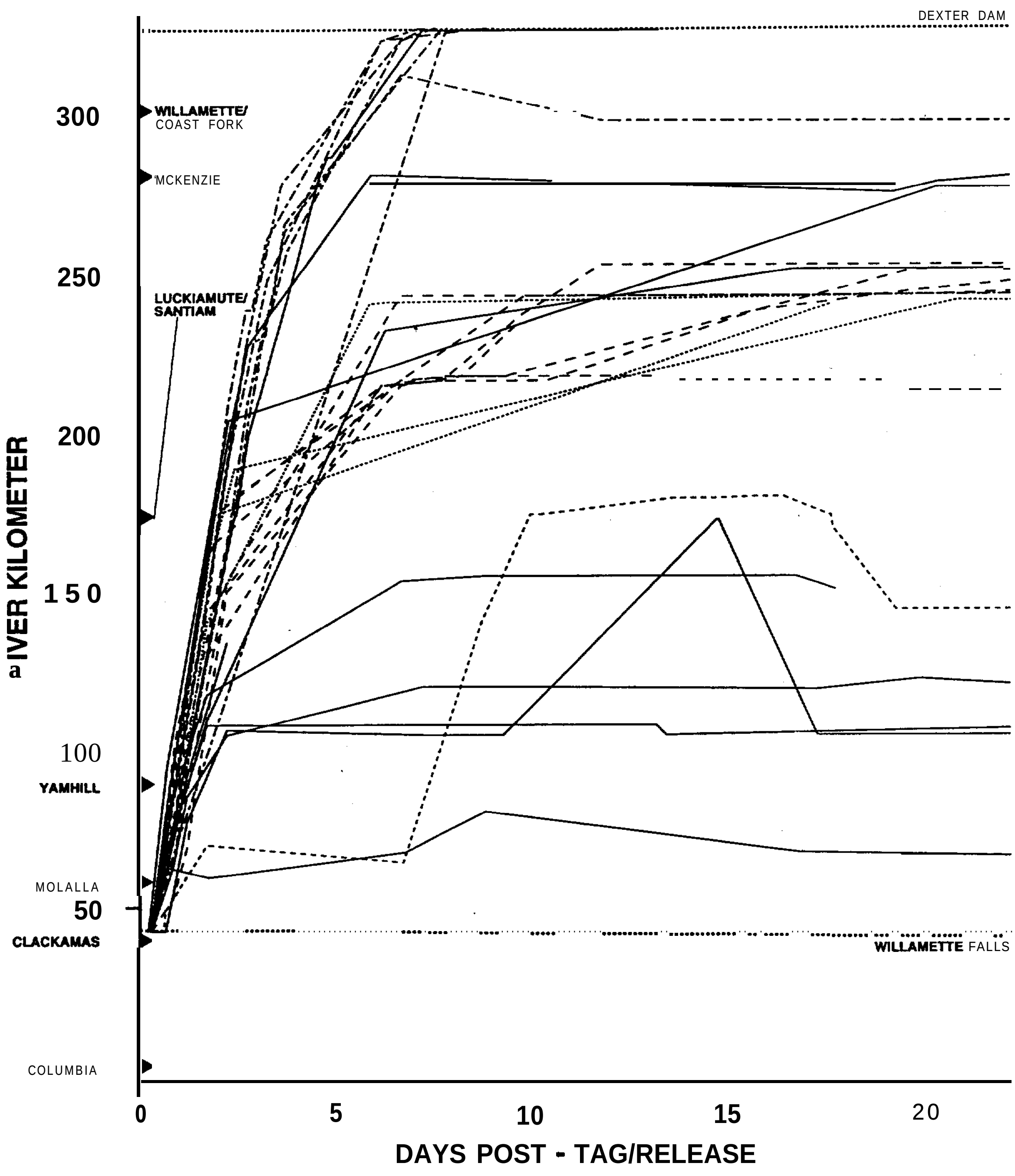


Figure 14. Location and movement of mid-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1992. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Fish which swam into the McKenzie River denoted by mixed dashed lines; North Santiam River by bold dashed lines; South Santiam River by narrow dashed lines; fish remaining in the Willamette Falls by solid lines. Day 0 = 14/15 May; N = 30.

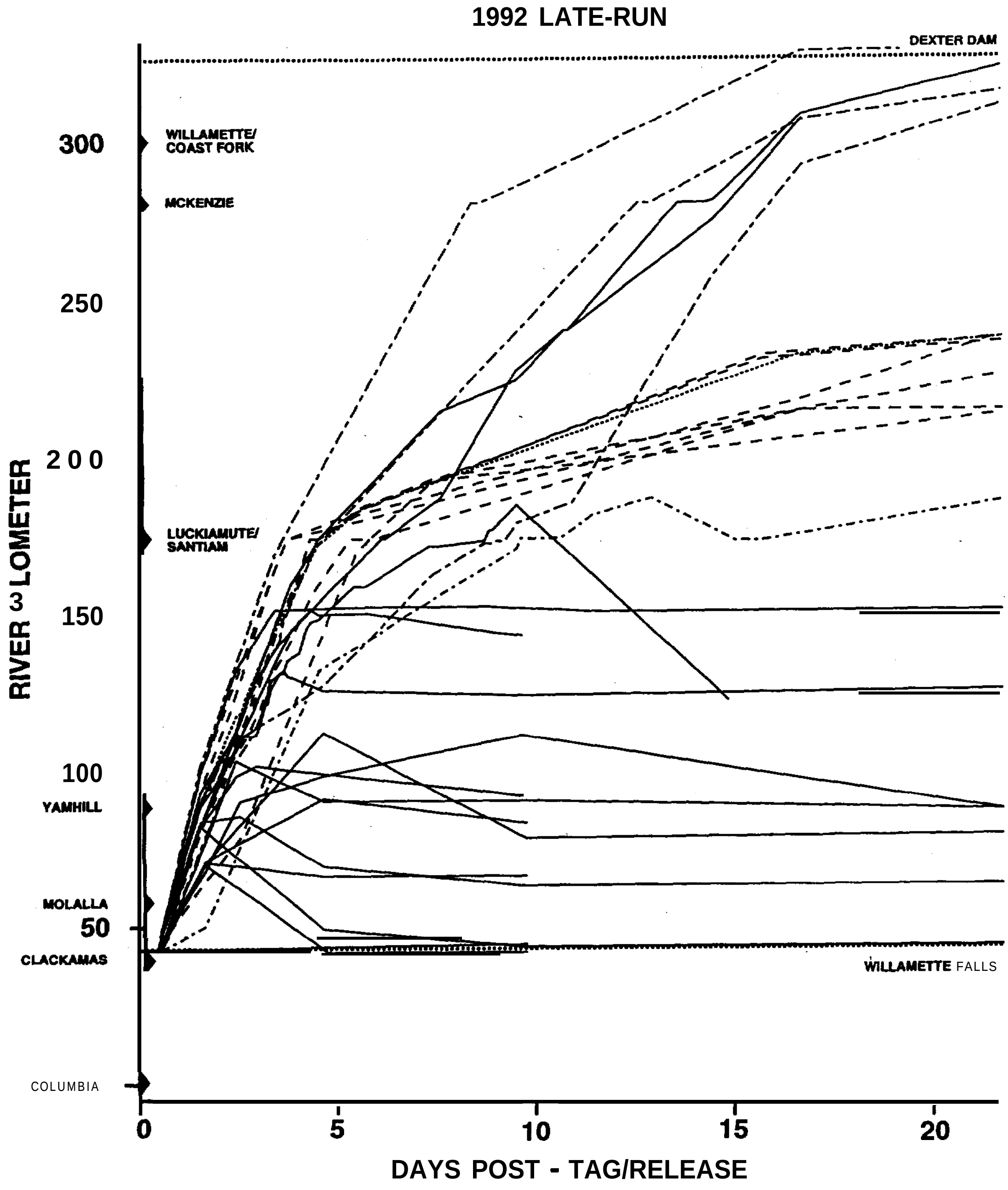


Figure 15. Location and movement of late-run adult spring chinook salmon given stomach-implant radio transmitters and released at Willamette Falls in 1992. Each line represents an individual fish. Release and hatchery locations shown by horizontal dotted lines. Important tributaries of the Willamette River indicated by arrow points on ordinate. Fish which swam into the McKenzie River denoted by bold mixed dashed lines; North Santiam River by bold dashed lines; South Santiam River by narrow dashed lines; fish remaining in the Willamette Falls by solid lines. Day 0 = 8 June; N = 28.

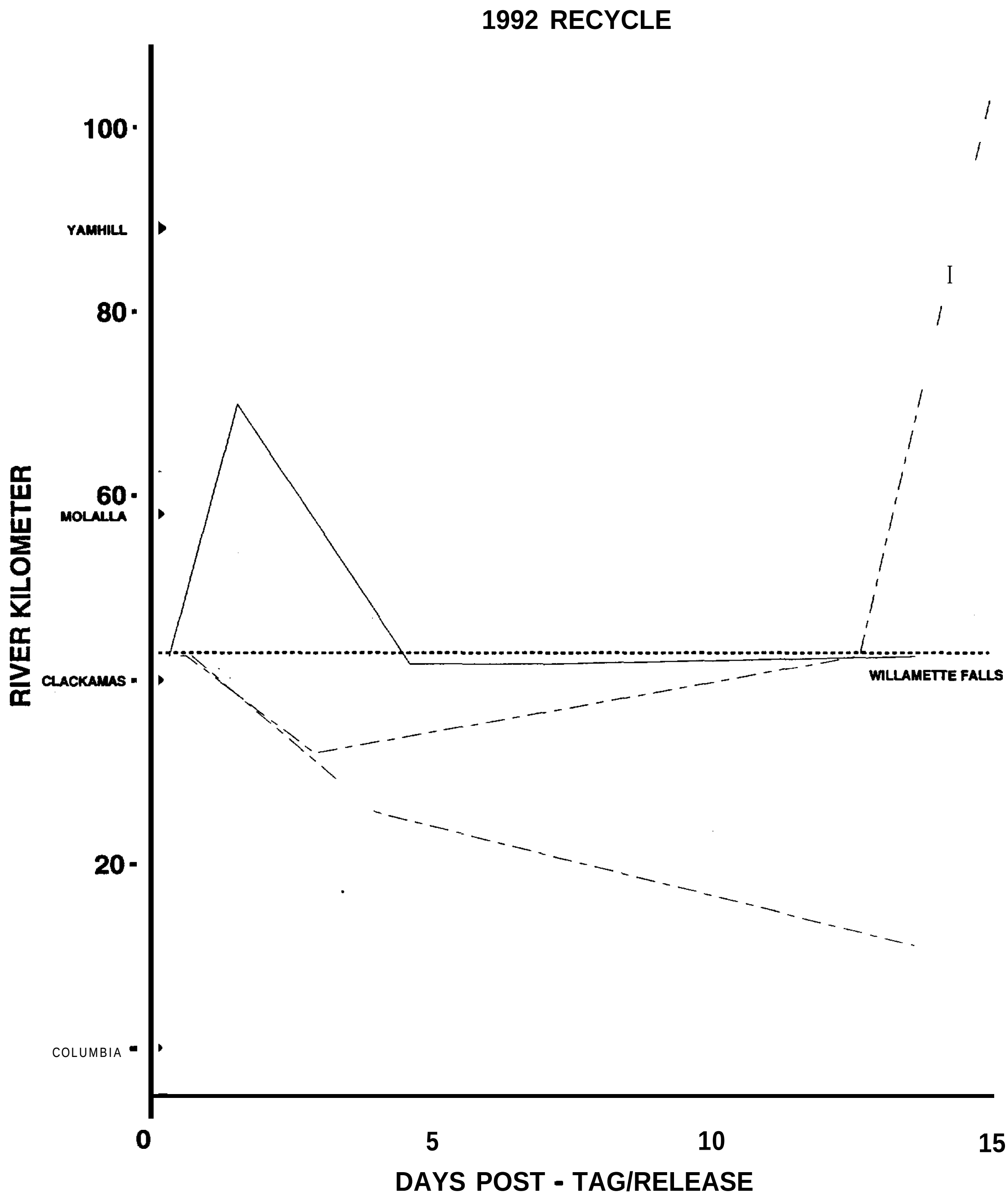


Figure 16. Detailed movements of adult spring chinook salmon radio tagged in 1992 which went below Willamette Falls; some of which made additional passes through the fishway. Early-run fish noted by dashed and dotted lines; late-run fish by solid lines. Data from Figures 13 - 15.

those marked) did also. One fish moved up into the **Mainstem** Santiam then fell back to above Salem and probably died there.

We tracked **28 late-run adult spring chinook** salmon tagged on 8 June for up to 3 months (Fig. 15). This group left the falls area like their earlier cohorts, and those which moved over the first week maintained speeds of from 19 to 29 km/d on average.

Eight fish (29%) reached hatchery traps at Dexter, McKenzie, Foster or Minto. Anglers retrieved transmitters from four other fish they caught. Sixteen fish traveled in the Willamette River no further than the Santiam River confluence, therefore we cannot determine where they were headed. We know that three of these died, and believe that-the remainder died downriver, far from spawning areas. One of these actually swam 8 km up the mainstem Santiam River, backed up into the Willamette River, and swam up to Albany; its tag was found near Bowman Park.

Only two fish backed up below the falls (Fig. 16). One ultimately reached Dexter holding ponds (above). We lost track of the other down near Portland.

Temperature and Flow

Water temperatures (recorded at Willamette Falls) and flow rates (recorded at Salem) characterizing the Willamette River during the various phases of the adult run are presented in Figs. 17-20. In 1989 we were tracking adults during a relatively high flow event, associated with low temperatures (13 °C). Following tagging of early run adults in 1990, a far more significant flood event and its concomitant lower temperatures occurred. During the mid part of the run a smaller flood event occurred. During the late part of the run flows were significantly reduced and temperatures elevated. In 1991 another major flood event coincided with release of mid-run adults (but did not apparently influence the behavior of this group of fish). In 1992, a dry and hot spring, early run adults were tagged in association with the only flood event of the year (flow approaching 40 kcfs). When mid-run adults were tagged flows were low and temperatures already elevated above similar periods in previous years.

Specific Characteristics of Movement

Path Followed. There was great variation in the exact upriver migration paths of the salmon, but in general they avoided shallow water (< 1.5 m deep) and current greater than 4 kmph. In some areas, such as just after a bend in the river their movements were within 5m of the bank and not in the deep channel.

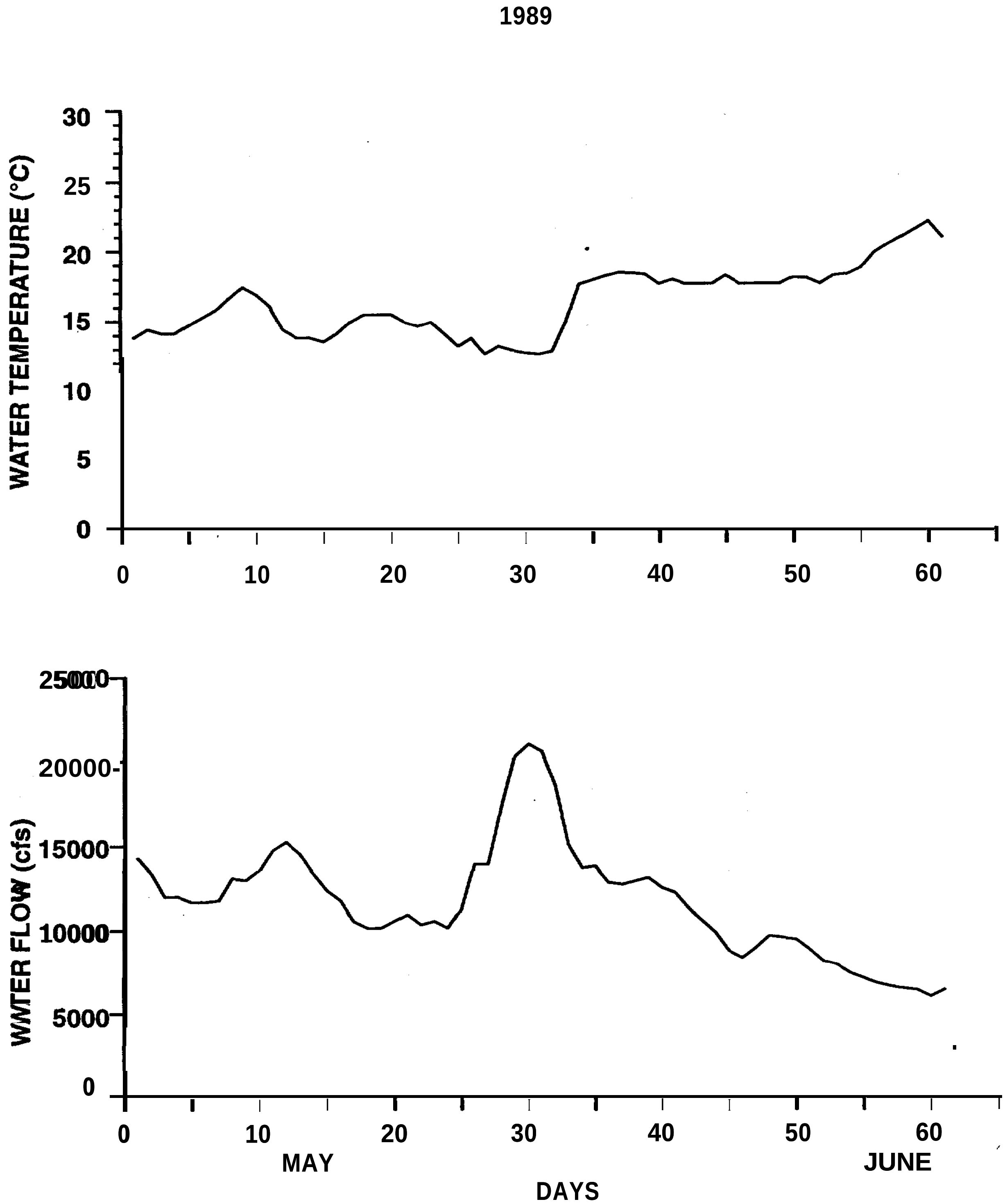


Figure 17. Hydrologic characteristics of the Willamette River during the adult spring chinook return migration, May and June 1989. Water temperatures recorded at Willamette Falls by ODFW; water flow recorded at Salem by U.S. Geological Survey.

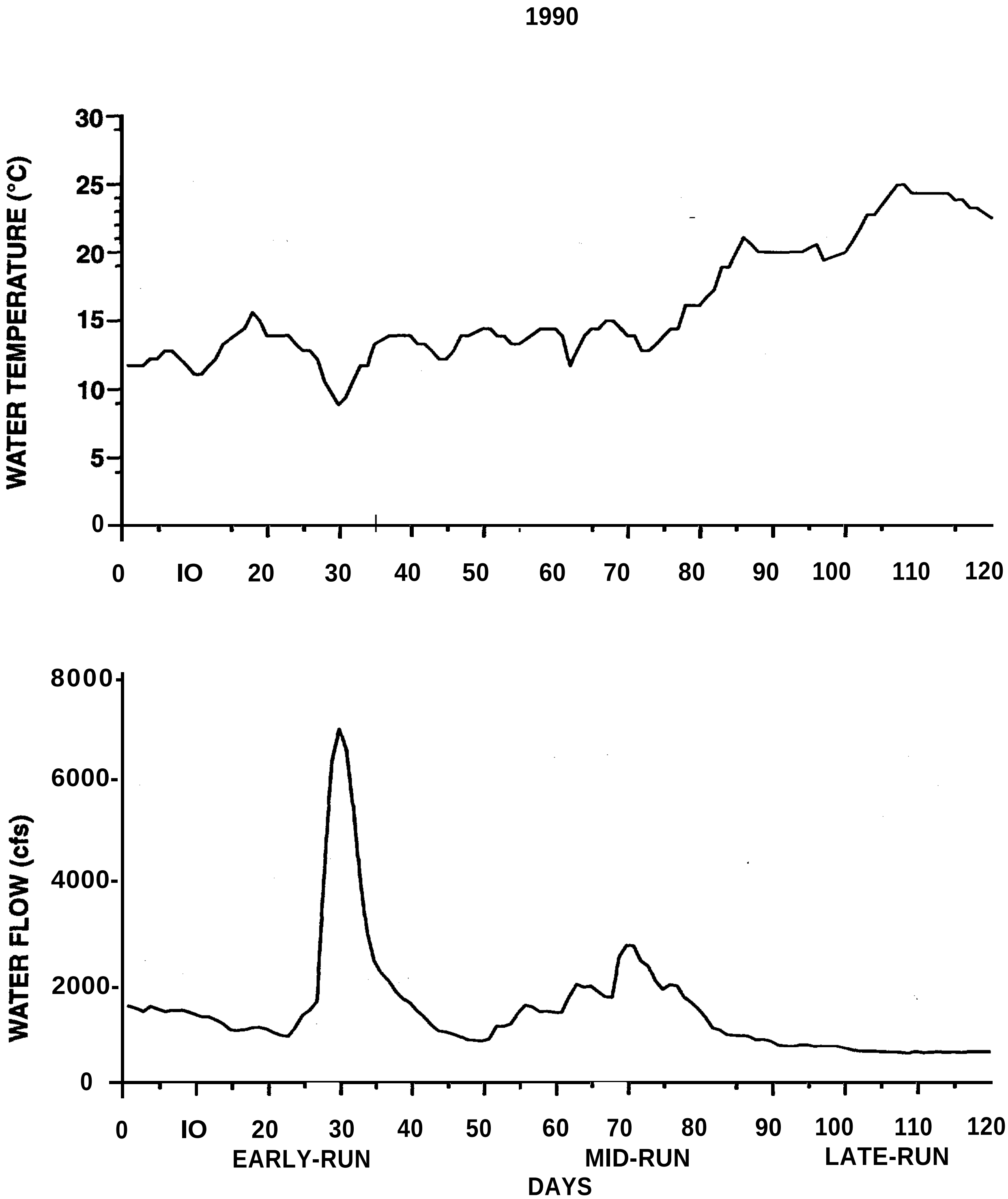


Figure 18. Hydrologic characteristics of the Willamette River during the phases of the adult spring chinook return migration, April to July 1990 (day 1 = 1 April). Water temperatures recorded at Willamette Falls by ODFW; water flow recorded at Salem by U.S. Geological Survey.

1991

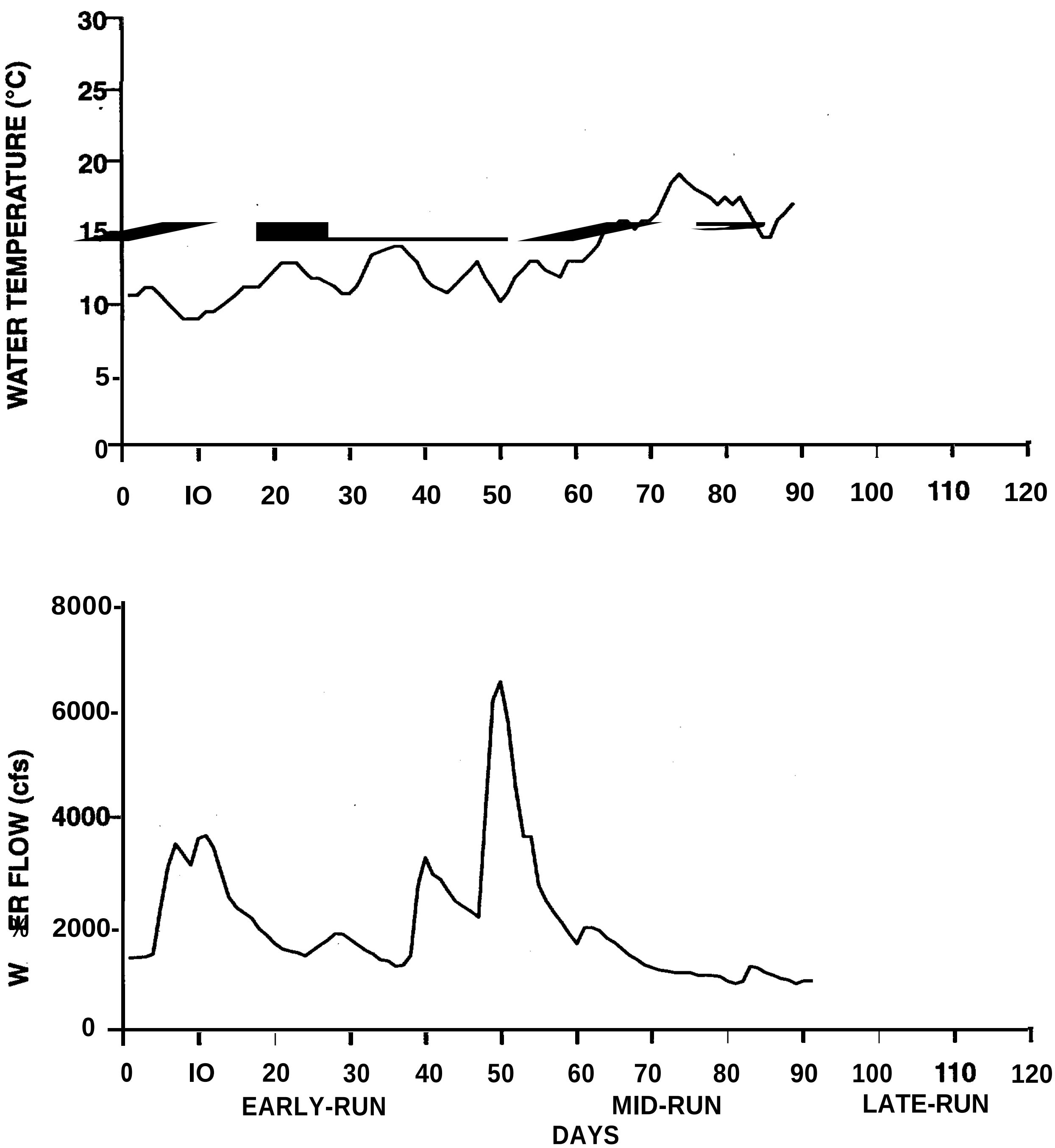


Figure 19. **Hydrologic characteristics** of the Willamette River during the phases of the adult spring chinook return migration, April to July 1991 (day 1 = 1 April). Water temperatures recorded at Willamette Falls by ODFW; water flow recorded at Salem by U.S. Geological Survey.

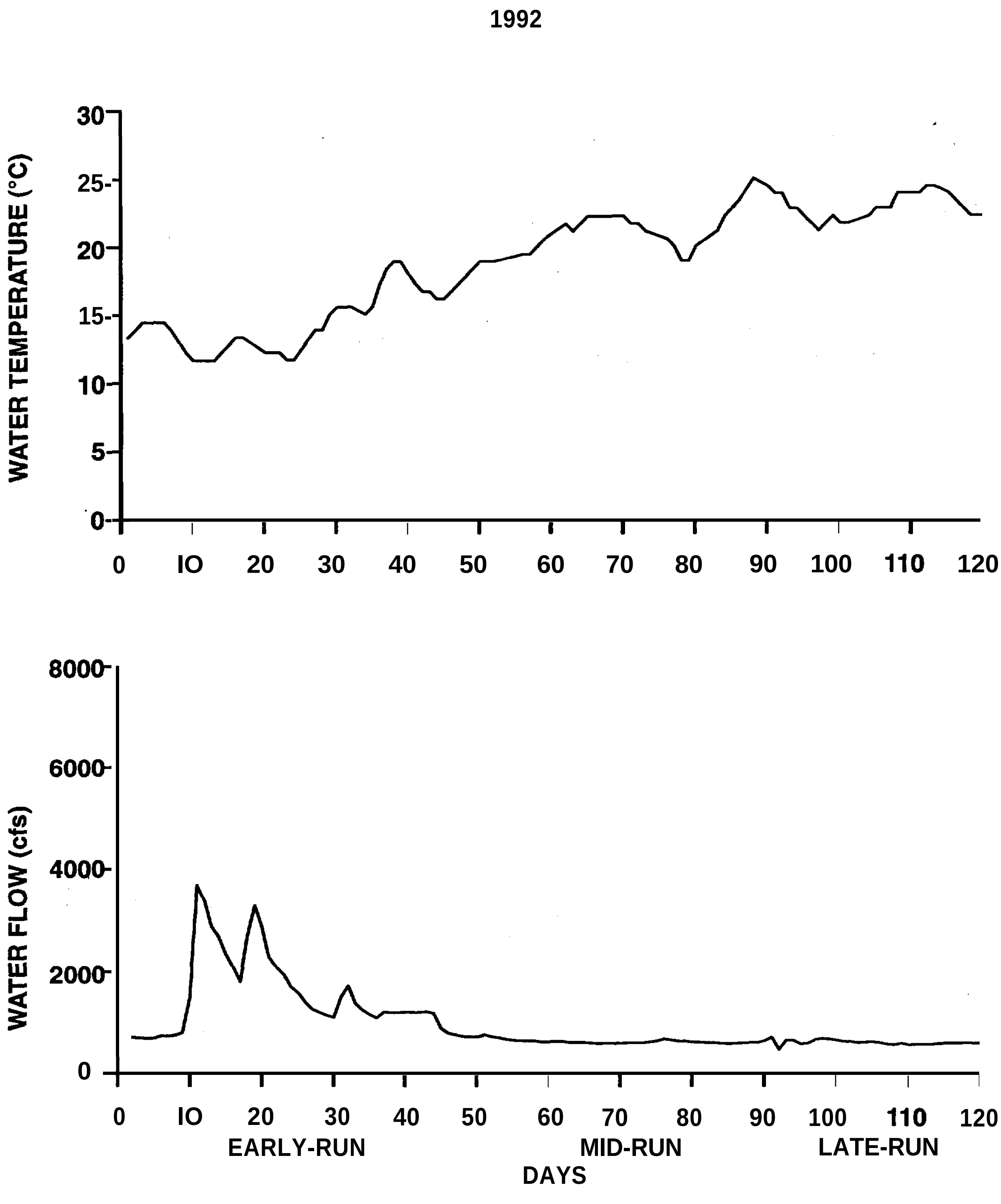


Figure 20. Hydrologic characteristics of the Willamette River during the phases of the adult spring chinook return migration,. April to July 1992 (day 1 = 1 April). Water temperatures recorded at Willamette Falls by ODFW; water flow recorded at Salem by U.S. Geological Survey.

Within the constraints mentioned above, different individuals traveled on different sides of islands, such as Wells Island near Buena Vista, or a smaller island near Sam Dawes and Buckskin Mary Landings between Peoria and Harrisburg.

Holding. Adults remained in the larger, deeper pools far upstream on the Santiam, McKenzie and Willamette Rivers for days at a time. These pools are probably staging areas after the main migration from which fish move out to spawn later in the summer. During the active migration fish held or rested in pools below riffles, or near the confluences where there was a temperature gradient. Some exceptions to this were found in 1992 when two early run fish were located (30 April) around the confluence of the Willamette and Santiam rivers which then directly moved up the Santiam River. A group of late run fish between 12 and 15 June exhibited diverse behavior: six moved right into the Santiam River; and four remained in about 3 m of water from 3 to 7 h. Two late run fish waited at least 2.5 h at the confluence of the North and South Santiam rivers. One early run fish moved very slowly up through the McKenzie and Willamette confluence, less than 2 km in four hours. And two late run fish spent from 8 to 17 h here before moving through. (See also results for 1990 mid-run fish which slowed by 60% after reaching the McKenzie).

Continuous tracking. We maintained continuous (24 h) surveillance by boat of four late-run adults over 46 h from 10-12 June 1992, in the middle Willamette River between Wheatland Ferry and Independence. Three fish maintained an average speed of 17 km / day (Fig. 21). Their movement did not vary with a diel periodicity. Three fish which stopped for several hours, did so during daylight; they held in pools below riffles. Three fish which were stationary when we last located them, died; one fell back more than 17 km to where we found its tag on the bank. Two fish which were moving upstream at 17 km / day when we last heard them reached hatcheries on the North Santiam and McKenzie Rivers. Sky conditions were partly cloudy during these observations, with daytime temperatures around 20 °C.

Temperature and refugia

We implanted 10 temperature sensing tags in salmon during 1992. One of the mid-run fish experienced a rise in temperature of 2 °C as it ascended the Willamette River to the mouth of the McKenzie River; thereafter in the upper pools of the Mckenzie River near Leaburg Dam it found water cooler than in the mainstem. (Fig. 22). One late run fish which we tracked for several days (see above) did not ascend far above the Santiam / Willamette river confluence, and its temperature remained about the same as when tagged; it died (Fig. 23). The temperature recorded from these fish did not differ significantly from water's surface temperature (fig. 24), even in areas of the Mckenzie and North Fork of the Santiam rivers. Either there were no cold water refugia in the Willamette

Figure 21. Upriver progress of five individual late-run adult spring chinook salmon tracked continuously between the vicinities of Wheatland Ferry and Independence. Shaded areas indicate periods of darkness. Solid, heavy dashed, and dotted lines, three fish died in Willamette River; mixed dashed line, fish arrived at hatchery terminus on North Santiam River; light dashed line, fish arrived at hatchery terminus on McKenzie River.

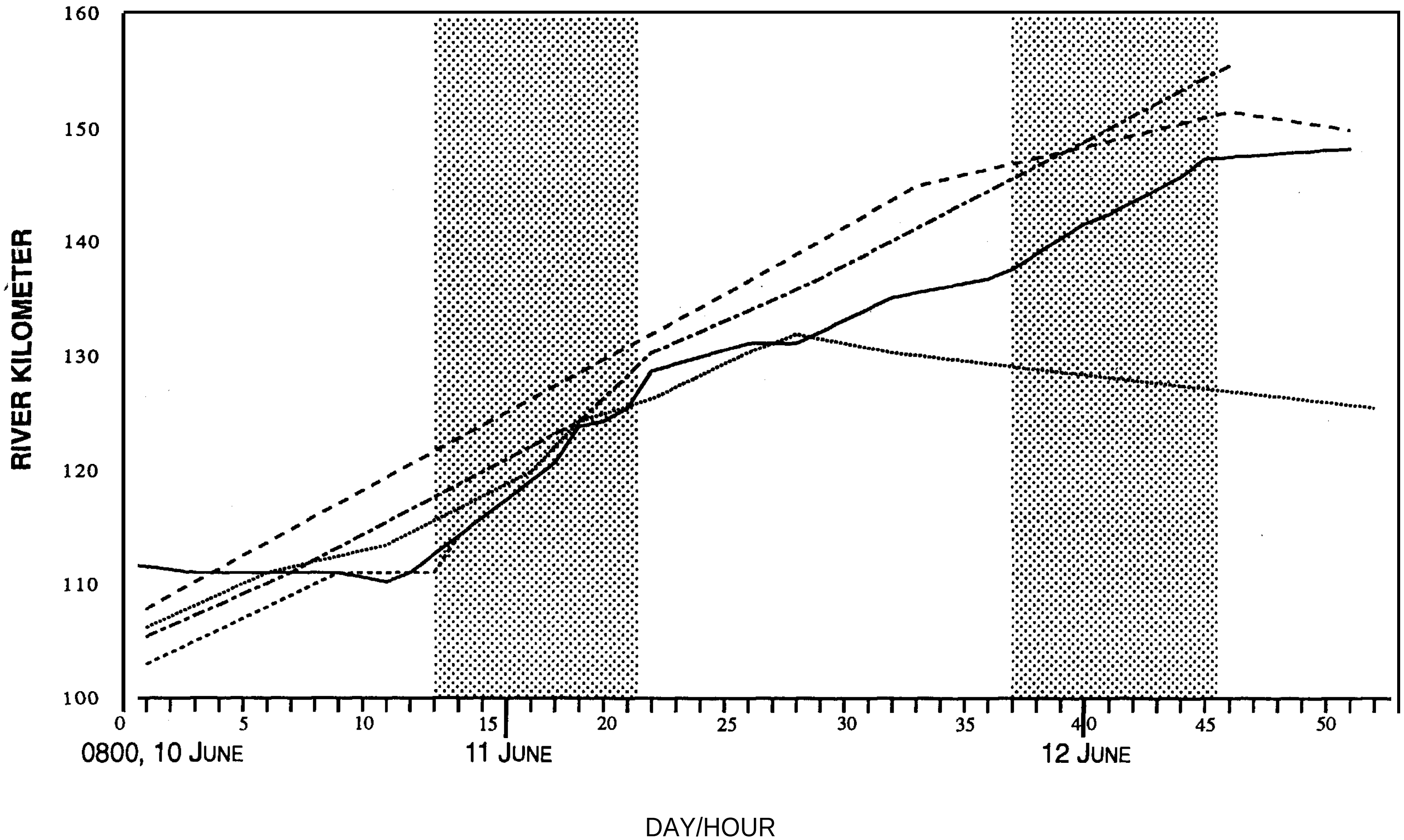


Figure 22. Water and body temperature record of mid-run adult spring chinook salmon (1992) followed from Willamette Falls to Leaburg Dam on the McKenzie River. Fish body temperature measured with a temperature sensing unit, part of the radio transmitter in its stomach.

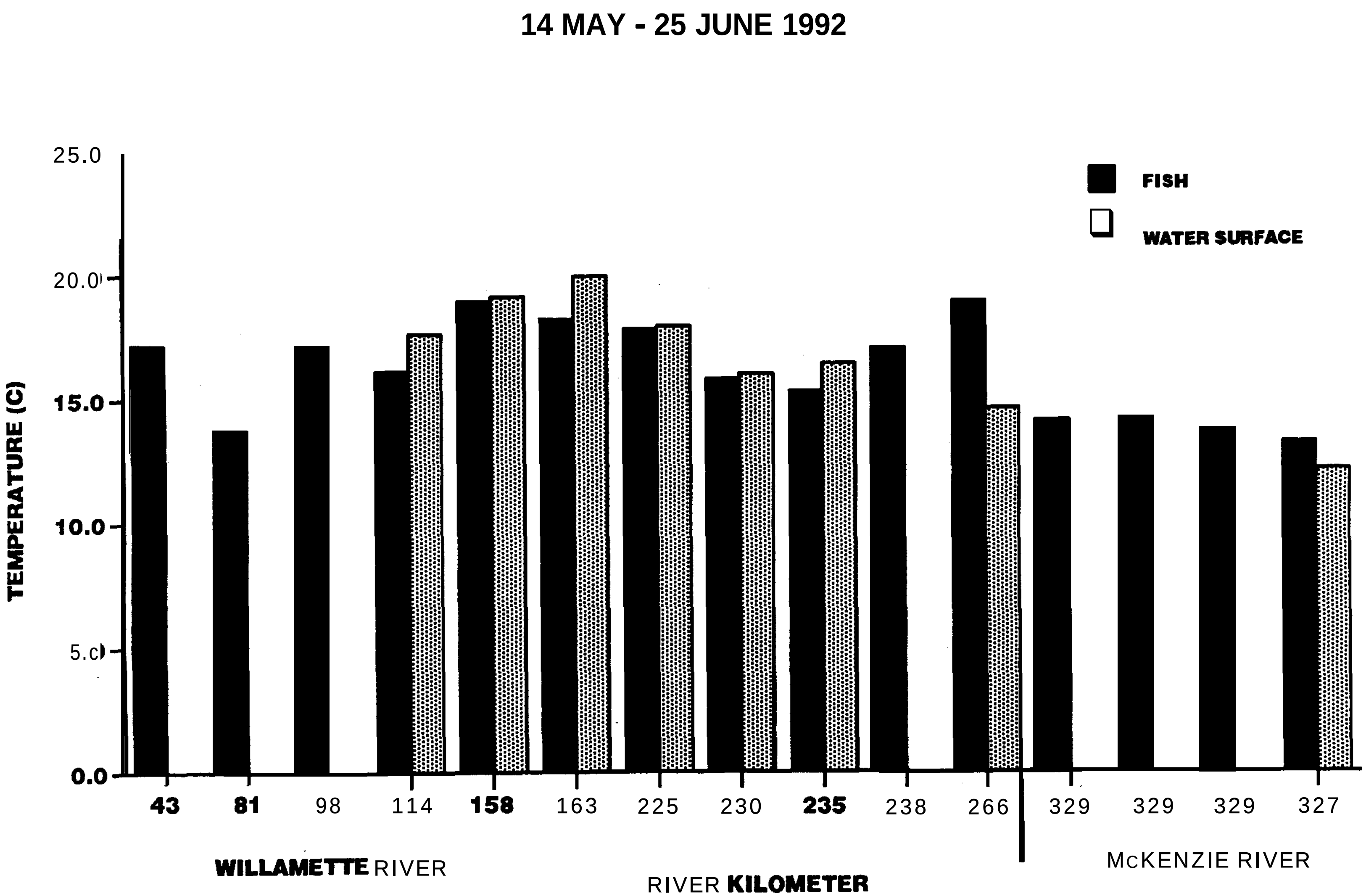


Figure 23. Water and body temperature record of late-run adult spring chinook salmon (1992) followed from vicinity of Newberg to Albany. This fish died. Fish body temperature measured with a temperature sensing unit, part of the radio transmitter in its stomach,

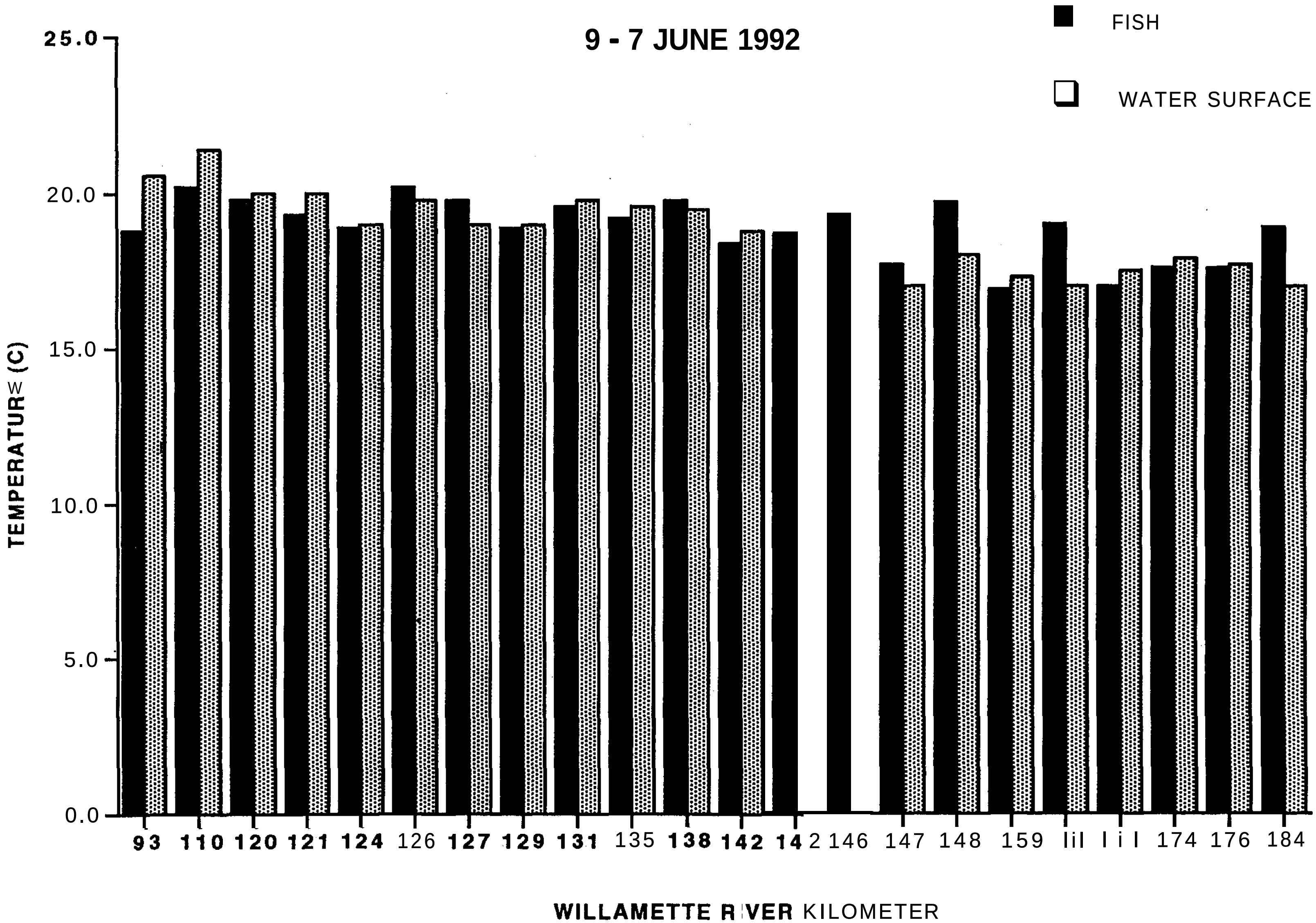
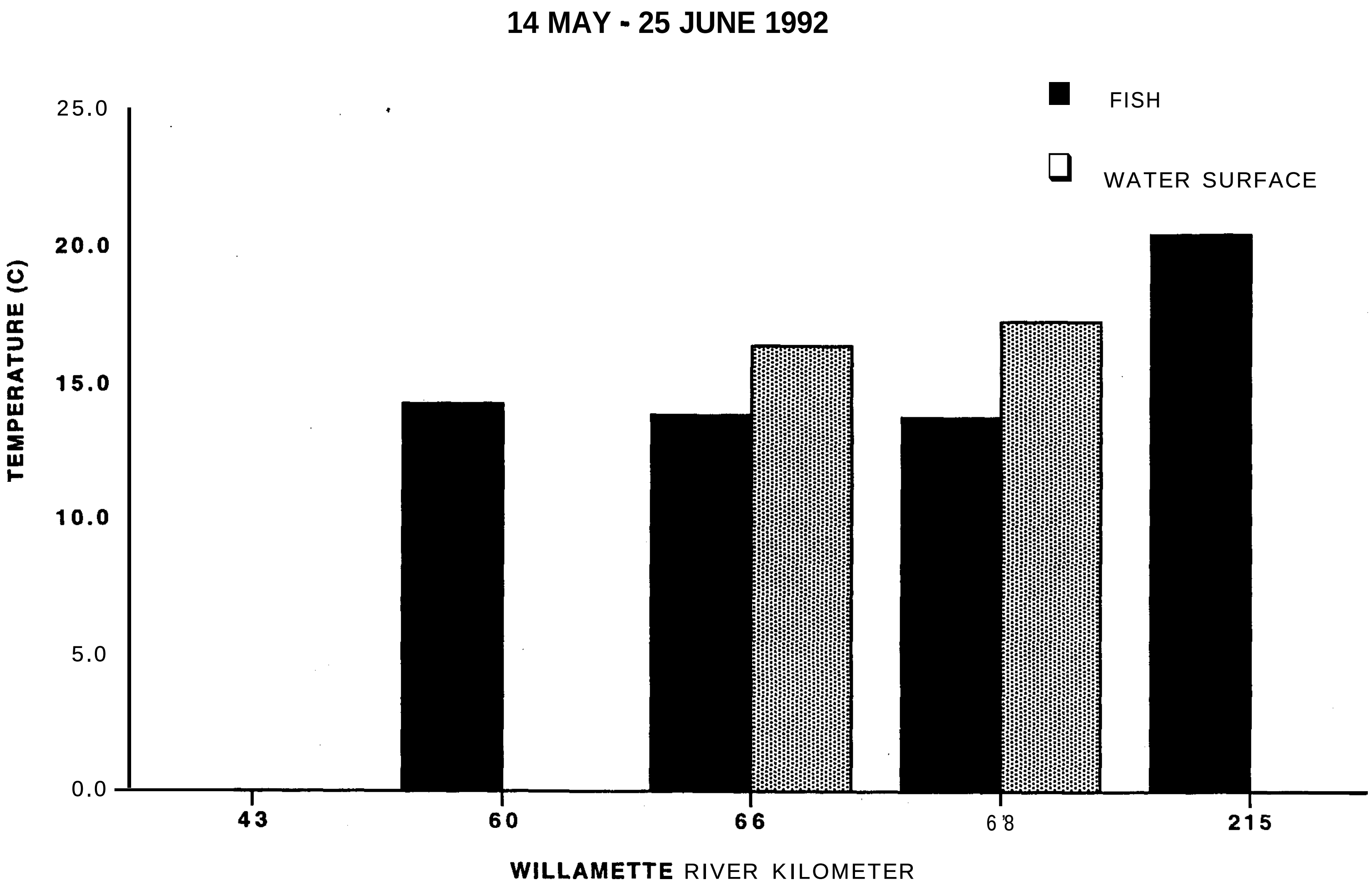


Figure 24. Water and body temperature record of mid-run adult spring chinook salmon (1992) followed from vicinity of Wilsonville to Corvallis. Fish body temperature measured with a temperature sensing unit,. part of the radio transmitter in its stomach.



system, or we were not able to record subtle differences important to the fish. Similar conclusions were reached in another radio-tagging study of spring chinook on the McKenzie River *(Radio-trucking studies of adult spring chinook salmon migration behavior in fhe McKenzie River, Oregon.* EA Engineering, Science and Technology, Lafayette, CA. 1991)

Low-flow Blockage

In 1992 twenty two (27%) of our tagged fish migrated up the North Santiam River. Six fish remained in the Stayton area, "blocked" from migration by low flows for extended periods: three fish remained at least 3 to 5 days before moving on; one fish was caught after a minimum of 38 days at that location; one fish died (we found its transmitter); another individual most likely died also. The most critical period of blockage was the last week in May. Our data show that fish remained "blocked" in the so-called "Snag Hole" between Lower Bennet Dam and the Stayton Bridge. Here water flow was insufficient to allow passage up the dam's ladder, as well as the Pacific Power and Light (PPL) head gate ladder into the power channel. At times PPL reduced power production, allowing enough water to spill through their ladder so that fish passage was possible. Those fish which were blocked, but subsequently moved on, either 1) found passage through PPL head gate or less likely through Lower Bennet ladders, or 2) backed downstream and entered the power channel downstream. From May onward, the south channel of the North Santiam was essentially de-watered.

Salmon Mortality

In 1990 we encountered many salmon carcasses in the Willamette above Albany (River KM 193) in Mid-July. In 1991 we encountered carcasses in late June around Salem (River KM 137), then in the upper river around Eugene (River KM 290) during July.

In 1992 we began to encounter dead fish in early May, as far down river as San Salvadore (River KM 97). We were located the carcasses of several radio-tagged salmon by homing in on temperature transmitters which were pulsing rapidly in the heat out of water. In each case all that remained of the fish which had been alive the week before were a few scales and dispersed fins or bones. Turkey Vultures (*Cathartes aura*) were commonly seen feeding on the carcasses of chinook salmon during our studies, and once we found a vulture feather and fecal material near the remains of a fish and its transmitter. Something removes salmon carcasses from the river, consumes them, and thus transfers the biomas from the aquatic to terrestrial food chain; see Tables 2-4.

Table 2. Summary of the rivers traveled and condition when last found for 25 early-run spring chinook salmon radio-tagged in 1992. Numbers refer to individual fish.

CONDITION	RIVER				
	WILLAMETTE	MAIN SANTIAM	NORTH SANTIAM	SOUTH SANTIAM	MCKENZIE
TAKEN AT HATCHERY	1		1	1	
REACHED HATCHERY AREA	3'		3		
ANGLER CAUGHT		1c	1	2	1
DIED					
UNKNOWN	5 d,g		3 b,e	1a	2f
TOTAL	9	1	8	4	3

a: fish traveled **3** km up Willamette river, then fell back to Willamette Falls

b: fish traveled 12 mi up river, then fell back to Newberg

c: fish traveled 10 km up river, then fell back to Wheatland and was caught

d: fish fell back to Willamette river kilometer (RKM) 11

e: tag found on Willamette river bank

f: tag found on river bank 24 km below hatchery area where fish last heard

g: fish went 2 km up Luckiamute River (RKM **174),** then fell back 52 km and presumably died in the Willamette River

Table 3. Summary of the rivers traveled and condition when last found for 30 mid-run spring chinook salmon radio-tagged in 1992. Numbers refer to individual fish.

CONDITION	RIVER				
	WILLAMETTE	MAIN SANTIAM	NORTH SANTIAM	SOUTH SANTIAM	MCKENZIE
TAKEN AT HATCHERY			1	1	5c
REACHED HATCHERY AREA			2	2	1
ANGLER CAUGHT			2	1	
DIED	2a				
UNKNOWN	9b	1d	2		1
TOTAL	11	1	7	4	7

a: two fish stopped migrating; tag found in remains on bank

b: one fish reached Santiam/Willamette river junction, then fell back 68 km

c: one fish traveled up to Blue River, then fell back to hatchery 32 km

d: one fish traveled up Santiam River 8 km, then fell back 45 km and probably died

Table 4. **Summary** of the rivers traveled and condition when last found for 28 late-run spring chinook salmon radio-tagged **in** 1992. Numbers refer to individual fish.

CONDITION	RIVER				
	WILLAMETTE	MAIN SANTIAM	NORTH SANTIAM	SOUTH SANTIAM	MCKENZIE
TAKEN AT HATCHERY			4		1
REACHEDHATCHERY AREA	1		1		
ANGLER CAUGHT			2		2
DIED	3a				
UNKNOWN	12	1			
TOTAL	16	1	7	1	3

a: tags found near remains of fish

Passage Near Pope and Talbot Outfall at Halsey

In 1992 we encountered two mid-run adults moving at mid-day in the effluent plume (the water is often discolored for 10 km below) from the paper mill at Halsey (River KM 241). Both were moving continuously and rapidly (19 km/day).

DISCUSSION

Patterns of Movement

Although we have separated returning adults into early, middle, and late categories, this separation is arbitrary, and all upstream migrants might be more properly viewed as belonging to the same continuum (as illustrated by cumulative fish counts depicted in Figure 3). A general inspection shows the bulk of the run between mid-April and mid-June with clear inter-month differences in passage often corresponding to our grouping. Nevertheless, the different groups of fish followed do in fact represent different segments of that continuum, and several interesting observations emerge from their comparison.

One of the most apparent differences among the different phases of the adult run is that while mid-run and (to a lesser degree) late-run fish exhibited a tendency to resume upstream migration at a relatively rapid pace in the days immediately tagging and release, and made considerable progress upstream, the majority of early-run fish did not.

A partial explanation for this apparent difference may have to do with the influence of water quality on adult chinook behavior. During the week following the tagging of 1990 early-run fish, the Willamette Valley experienced rain on an almost daily basis. The Willamette River flooded its banks, islands were temporarily submerged, trees were swept downstream, and the quantity of suspended solids in the water increased (resulting in near zero visibility). From an objective standpoint, the hydrologic data presented in Figure 18 illustrate the dramatic changes in water flow and temperature which occurred during this period. Early-run fish were tagged and released on 20 April, corresponding to day 20 in Figure 18. At the end of the following week, water flow rates of 10,000-15,000 cfs increased to almost 70,000 cfs in only three days (Fig. 18, bottom). At the same time, water temperatures which had been 13-16 °C dropped to 8 °C (Fig. 18, top). These sudden and dramatic changes in water quality had a major influence on the behavior of upstream migrants is apparent (see Figure 3), which illustrates the recorded passage-of adult spring chinook through the Willamette Falls fishway. At the same time at which water flows peaked and temperatures dropped, daily fish counts at Willamette Falls, which had ranged from 1,000-1,500 fish/d, decreased to the point where daily fish passage was almost nonexistent (Fig. 3). If these environmental changes influenced the behavior of fish which were presumably healthy and normal (i.e., not subjected to anesthetization and tagging, or stressed by high water temperature), it is reasonable to expect that radio-tagged fish were equally affected and deterred in their upstream migration (assuming that the counts at the Falls are representative of general movement patterns upriver). On the other hand, these changes in water quality may not suffice as the only explanation for the lack of upstream progress for early-run fish. Figure 3 indicates that in the week following the flood, flows and temperatures stabilized at pre-flood levels and daily fish passage at Willamette Falls resumed and in fact reached a seasonal peak. It appears therefore that the apparent blockage of upstream migration was only temporary, and was greatest when flood stage conditions prevailed. Radio-tagged early-run adults which may have been blocked by flood conditions did not, however, demonstrate a marked tendency to resume upstream movement at this time. Other factors must have contributed to the fact that early-run fish did not, for the most part, migrate rapidly upstream.

In 1991 flood conditions (65,000 cfs) and low water temperature (10 °C) occurred about 20 May 1991 (Figure 19). This period corresponded to the end of our tracking early-run adult spring chinook. Some radio-tagged fish had previously ceased migration, and the remainder were already high in the river (between Corvallis and Eugene). We expect that a group of spring chinook negotiating the lower river at this time would have exhibited markedly reduced rates of migration.

During the week of 12 June 1991 water temperature at Willamette Falls rose to 19 °C (Figure 19). This period corresponds to the end of our tracking mid-run fish and was prior to the late-run tracking. Thereafter temperatures gradually increased and flows decreased. Reduced flows and increased clarity could force fish, which previously had moved at all hours of the day, to only move now at night; but our data in from 1992 during record low flows and high clarity do not support this. Increased temperatures would promote fungal growth and increase other disease processes. Both factors could explai
In 1992 early-run fish migrated more like the previous years' mid-run group. The spring and summer of 1992 produced record low water flows and high temperatures (Fig. 20); spring heat and dryness came very early. Thus both early- and mid-run fish experienced greater mortality than in past years (see below).

In summary, our data for all parts of the run in 1990 and 1991 (both normal to high flow years) show early-run fish moving upriver furtively, and tending to be impeded by high flows and low temperatures or both, and some mortality, during the unsettled environmental conditions of early spring. Mid-run salmon moved swiftly and successfully upstream during mostly optimum conditions of mid-May and early June. Late-run fish largely move quickly upstream as do those in the mid-run, but most stop their migration and die before reaching the Santiam River confluence (River KM 174). By contrast, 1992 with early low flows and high temperatures, showed different patterns of behavior. Early-run fish corresponded more to the mid-run pattern described above. Whereas mid- and late- run fish followed the late-run pattern described above, most of these fish which remained in the Willamette River, headed for the McKenzie River or Dexter on the Willamette River Middle Fork, never reached their end point and probably died.

Having reached deep, cool pools (ca 13 °C) in the upper North or South Santiam River, McKenzie River or Middle Fork of the Willamette River, salmon may remain for several weeks or months. These pools are probably staging areas after the main migration from which fish move out to spawn later in the summer.

Discrepancies between Willamette Falls Window Counts and Spawner Counts Upriver

Mortality. The most obvious factor accounting for the apparent loss is mortality. Especially during the late phases of the adult study in all years we observed salmon carcasses, floating or stranded on gravel bars and riverbanks. It is likely that reduced water flows and accompanying high temperatures which prevailed at this time effectively shut down the return migration; many fish which **had** not reached the upper reaches of the river by this time may have succumbed to pre-spawning mortality. See Appendix A, a thesis by Caleb Slater that illustrates the impaired health of chinook salmon late in the run in the Willamette River system

Especially in the early spring and summer of 1992 diseases like columnaris, furunculosis, and bacterial kidney disease, probably extracted their toll early (Becker and Fujihara, 1978; see also USFWS fish disease leaflets). Of the test fish, we believe that a total of 2 of 5 five died in 1989 (40%), while in 1990, 1991, and 1992 the mortality was 14 of 48 (29%), 16 of 77 (21%) and 33 of 83 (40%). Therefore between 21 and 40% of the chinook adults counted at the Falls die naturally in the river before spawning.

Angling contributes also to a loss of some adult salmon. In 1990 none of our tags were returned by anglers. In 1991 nine of our fish were caught (12%), while 12 (15%) were caught in 1992. All sources of mortality thus contribute to a loss of up to 50% of adults reaching upriver hatchery or spawning locations. These mortality data alone would go far in explaining previously reported low percentages of spring chinook passing Willamette Falls that reach spawning areas (40-50%).

We know that something removes salmon carcasses from the river, consumes them, and thus transfers the biomas from the aquatic to terrestrial food chain. Cederholm et al. (1989) also found that experimentally introduced carcasses of adult Coho Salmon were removed from spawning streams in the Olympic Penninsula and consumed by 22 species of mammals and birds. The distances carcasses traveled appeared to be directly related to the occurrence of freshets and inversely to debris load and carnivore scavenging.

Salmon which moved back below Willamette Falls. Of particular interest are the adults which we observed to fall back below Willamette Falls a few of which returned to the Columbia River, some reentered the **fishway** to go back upstream, some of which entered the Clackamas River, but most probably die. In 1990 five of 48 (10%) radio-tagged fish which exited the Willamette Falls **fishway** demonstrated this kind of behavior. In 1991 nine of 77 fish (12%) fell back, and only three tagged fish (4%) did so in 1992. Considering that the cumulative count of adult spring chinook salmon recorded past Willamette Falls at the end of July has ranged from 40,000 to 69,000 fish, a rather substantial number of fish assumed to move exclusively upstream may, in fact, never do so or perhaps be counted twice, some more than that. Fish which fall back through the ladder are subtracted as they pass the counting window, but those which fall over the falls and swim back up through the ladder would be counted twice. These events are another source of discrepancy in accounting for the fish between Willamette Falls and headwater areas.

The subsequent behavior of these "fall- back" fish remains a mystery. It seems reasonable, however, to suppose that these individuals either remain in the lower Willamette River (in which **case** they would be re-subjected to rather intense sport-fishing pressures below Willamette Falls), exit the Willamette and run up the Clackamas River (we documented such behavior for one fish), or exit the Willamette and continue up the Columbia (or a Columbia River tributary), possibly as far as the Upper Columbia or Snake Rivers. It would be very interesting to initiate research directed towards gaining a further understanding of this aspect of "Willamette River" spring chinook migration, particularly in light of current discussions surrounding the depletion of upper Columbia and Snake River salmon stocks, related to straying phenomena especially.

For 1992 our data suggest that fewer than expected numbers of radio-tagged adults traveled up the Willamette River as far as Dexter Ponds , while an unexpectedly large number of adults traveled up the North Santiam. In addition several fish from each part of the run, made long journeys up the Willamette, even into the Santiam River, before moving back downstream. While we cannot know the river of emigration for any of our fish, there are several potential explanations for this behavior, including temperature stress and fish selecting the first cool tributary (the Santiam River), and- disease (temperature related?) causing fish to sicken, become disoriented, and die. An additional possibility is straying because of incomplete or ambiguous imprinting. In January 1990 ODFW released 71,881 smolts reared at Willamette Hatchery just below Willamette Falls. An expected 1,000 to 2,000 adults would return from these releases starting with three year old fish in 1992; these fish which could be expected to have reduced homing ability.

Implications for the Oxygenation Study

Our work was begun as an element in the ODFW oxygenation study relating hatchery practices to smolt behavior and survival measured as returning, coded wire tagged adults. Several findings from our studies are worth considering, now that the first adults released as treated smolts have returned (1992 was the fi-styear that any fish handled as part of the oxygenation study may have returned). First, after mortality as emigrating smolts and ocean-growing juveniles, returning adults experience up to 50% mortality in the Willamette River. Implications for reduced sample size are clear. Second, if rearing conditions as juveniles affect the timing of adults returning, then different segments of the adult run may be exposed to different river conditions, viz. flow, temperature, turbidity. And these in turn may expose the fish to different sources of in-river mortality. Therefore, treatment effects of hatchery rearing may be partially masked by incorrect smolt release times resulting in variable adult survival in the river (see also our juvenile reports).

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Appendix A.

An abstract of the thesis of Caleb Hood Slater for the degree of Master of Science in Fisheries and Wildlife presented on October 31, 1991.

Title: Sex Steroids, Gonadotropins, and Effects on the Immune Response in Maturing Spring Chinook Salmon (*Oncorhynchus tshawytscha*).

Plasma concentrations of 17β-estradiol, 17α,20β-dihydroxy-4-pregnen-3-one, androstenedione, testosterone, 11-ketotestosterone as well as gonadotropin I and II were measured in maturing adult female spring chinook salmon (*Oncorhynchus tshawytscha*) between April and September while migrating in the Willamette River and later while being held in hatcheries. Ovaries were also collected and their state of maturity determined. Steroid profiles were related to sample date and stage of egg maturity.

Plasma testosterone concentrations remained unchanged during the spring and early summer. In mid-July testosterone concentrations began to climb and reached maximum levels by the time spawning took place in September. 11-ketotestosterone was found in low concentrations throughout maturation, demonstrating a slight but significant rise just prior to spawning. Androstendione and 17β-estradiol concentrations were generally high throughout maturation, dropping significantly at the time of spawning. 17α, 20β-dihydroxy-4-pregnen-3-one was detected at very low concentrations throughout maturation, demonstrating a rapid and significant rise to high levels at the time of spawning. In 1989 the gonadotropins were detected at low levels throughout maturation. Gonadotropin I increased only slightly at the time of spawning, whereas gonadotropin II demonstrated a dramatic and highly significant rise at the time of spawning. Gonadotropin I concentrations were much higher during the 1990 season, reaching maximum levels late in the summer then dropping significantly at the time of spawning. The profile of gonadotropin II levels during 1990 was very similar to those recorded in 1989.

From April until the end of June, all oocytes had central germinal vesicles. In July germinal vesicles were migrating, and by the end of August germinal vesicles were peripheral In early September oocytes began to show germinal vesicles breakdown and ovulation occured in mid-September.

Male spring chinook were sampled in 1990. Circulating 11-ketotestosterone concentrations were stable throughout the spring and summer, rising significantly to maximum levels shortly before spawning. Plasma testosterone concentrations fluctuated during April and May, stabilized in June, then started a steady and significant increase to maximum levels at spawning. Androstenedione concentrations showed no significant differences in mean values over time, but the maximum individual levels were measured just before spawning. 17β-estradiol and 17α, 20β-dihydroxy-4-pregnen-3-one concentrations were very low throughout maturation. Gonadotropin I concentrations remained unchanged through most of maturation, rose to maximum levels late in the summer, then dropped significantly just before spawning. Gonadotropin II was present at low levels throughout maturation, increasing only just prior to spawning.

Cortisol, a steroid hormone, is a known immunosuppressive agent in fish, and sex steroid hormones, specifically testosterone and 17β-estradiol, are known to affect the mammalian immune response. To determine if the high

concentrations of sex steroids detected in the plasma of maturing spring chinook have any effect on the function of the immune system, leukocytes from the anterior kidney of juvenile spring chinook salmon were incubated in the presence of steroid and their ability to form specific antibody producing cells was used as a measure of immunocompetence. Testosterone and cortisol. but not **17β-estradiol** or **aldosterone,** were found to **significantly** reduce the plaque forming response ***in vitro.*** Testosterone and cortisol administered together had a **significantly** greater effect than did either when administered alone. Testosterone did not produce any immunosuppressive effects ***in vivo.***